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MODELING HYDROLOGIC IMPACTS OF TRIBAL WATER RIGHTS QUANTIFICATION AND SETTLEMENT ON THE FLATHEAD INDIAN IRRIGATION PROJECT

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By

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Modeling Hydrologic Impacts of Tribal Water Rights Quantification and Settlement on the Flathead Indian Irrigation Project

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The Confederated Salish and Kootenai Tribes (CSKT) of the Flathead Reservation are a federally-recognized group of tribes (Kootenai, Salish, and Pend d'Oreille) located in western Montana. On the reservation lies the expansive Flathead Indian Irrigation Project (FIIP), which supplies irrigation water to approximately 127,000 acres of tribal and non-tribal agricultural land. The 1904 Flathead Allotment Act opened "surplus" land to non-native homesteaders without tribal consent, initiating the land ownership fragmentation observed on the reservation today. This legacy, combined with historically unquantified tribal reserved water rights and the antiquated state of the FIIP infrastructure, including water losses from unlined earthen canals, decaying dams, and inefficient diversion points, make the FIIP extremely difficult to manage. In 2015, the CSKT, State of Montana (MT), and U.S. federal government completed decades of negotiations that ultimately quantified CSKT reserved water rights in a state-tribal water Compact; these quantifications are now codified in MT state law and are awaiting further approvals from the U.S. Congress and the CSKT membership. Compact provisions also attempt to provide adequate water to protect aquatic habit of culturally-significant fish species, such as endangered bull trout (*Salvelinus confluentus*), on and around the reservation through newly quantified instream flow water rights. The parties also negotiated terms of the CSKT Water Rights Settlement that seeks to resolve any future tribal water claims, and allocate federal funding aimed at rehabilitating and modernizing FIIP infrastructure. The Settlement awaits U.S. Congressional and CSKT membership approval to become law and be eligible for federal appropriation. The goal of this thesis research is to determine potential spatial variability in flow regimes under enforced Compact allocations before or in the absence of Settlement and FIIP rehabilitation. I approach these questions by employing the Soil and Water Assessment Tool (SWAT) to demonstrate how the Compact provisions will impact hydrology in the Lower Flathead River Basin, specifically in tributaries of the Flathead River where irrigated agriculture and CSKT instream flow rights coexist. Through modeling various scenarios, I found that future hydrologic variability (i.e., dry, normal, and wet years) will likely influence changing surface water hydrologic processes in the FIIP more so than irrigation efficiency and crop water demand, and thus climatic scenarios will likely determine whether tribal instream flow rights are adequate to protect aquatic habitat and species. Quantifying reserved water rights of federally-recognized tribal nations is vital for the enhancement of tribal sovereignty over water resources, economic development, natural resource management, and cultural and traditional practices. As with many tribes located in prior appropriation states, the CSKT has not had legally-enforceable water rights to allocate to other uses such as environmental flows for endangered species habitat until the recent Compact. However, in the absence of an approved federal Settlement, modeling and understanding contemporary FIIP flow conveyance regimes is critical for managing the watershed, tribal and non-tribal irrigated agriculture, and culturally-significant fish species habitat, especially in the absence FIIP improvements.

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CHAPTER 1. Introduction

The Confederated Salish and Kootenai Tribes (CSKT) of the Flathead Reservation are a federally recognized group of tribes (Kootenai, Salish, and Pend d'Oreillle) located in western Montana. The Hellgate Treaty of 1855 established the Flathead Reservation, however, much of the CSKT Nation was taken out of Tribal ownership during the land allotment era commenced by the U.S. government in the late 19th and early 20th century. On the reservation lies the expansive Flathead Indian Irrigation Project (FIIP), which supplies irrigation water to approximately 127,000 acres of tribal and non-tribal agricultural land. The Dawes Severalty Act of 1887 (Public Law No. 49-105) was extended to the Flathead Reservation through the 1904 Flathead Allotment Act (Public Law No. 159). The Dawes Act allowed lands previously protected in trust for Indians to be surveyed, assigned, and owned by individual Indians directly rather than held in trust for benefit of the Tribe as a whole. Once the land had been owned by an Indian for at least 2.5 years, the land could be permanently alienated by the Indian owner and transferred to non-native parties. The Dawes Act also allowed the government to purchase land that had not been allotted to individual Indians and later gave those lands to non-Indians for settlement (Walker & Baker, 2013). The legacy of the Dawes Act, perpetuated through the 1904 Flathead Allotment Act, is evident in the land ownership fragmentation observed on the Flathead Reservation today (i.e., checkboard of land ownership). As a result of the allotment era and associated Acts of Congress, the CSKT now find themselves a minority on their reservation (Walker & Baker, 2013); this is problematic.

The historic breakup of the Flathead Reservation combined with unquantified tribal reserved water rights, and an antiquated FIIP infrastructure, make the irrigation system on the Flathead Reservation extremely difficult to manage. The FIIP is located in Missoula, Lake, and

Sanders Counties of northwestern Montana, and as aforementioned, supplies irrigation water to approximately 127,000 acres (~514 km^2) of agricultural land (Voggesser, 2001). The project exists in a semi-arid region and has an average elevation of 1,950 feet (~594 m) (Voggesser, 2001). The project now includes fifteen reservoirs and dams, over 1,300 miles of canal and lateral systems, and over 10,000 minor structures for the diversion and control of the water supply. The sources of water for the FIIP originate primarily from: The Flathead, Jocko and Little Bitterroot Rivers; Mud, Crow, Post, Mission, Dry, Finley, Agency, Big Knife, Valley, and Fall Creeks (see Figure 4.2). Further, there are as many as 60 other small streams contributing to the FIIP system, and all these waterways cover a drainage area of approximately 8,000 square miles (~20,720 km^2) (Voggesser, 2001). The construction of FIIP began in 1908 and ended in 1963 (Voggesser, 2001).

Since 1992, the U.S. Bureau of Indian Affairs (BIA) has invested $22 million into the rehabilitation and betterment of the Flathead Project, particularly through its Safety of Dams Program, which is designed to assess problematic dam structures and identify future project improvements. The main concern of these studies focused on the determination of structures caused by aging. In May 2000, Sharon Blackwell, the Acting Deputy Commissioner of Indian Affairs (BIA), testified in a Senate Committee hearing on the Energy and Natural Resources Subcommittee on Water and Power that “efficient management of BIA irrigation operations continues to be a formidable challenge” because of the “antiquated” nature of equipment and structures (Blackwell’s testimony is found at *The Bureau of Indian Affairs Operation of the Flathead Indian Irrigation Project in Montana* (2000)).

When the Flathead Reservation was established in 1855, through the signing of the Hellgate Treaty, it also inherently established water rights for the Tribes in the process. As time progressed, these inferred water rights were not quantified or revolved in state or federal court, which is largely attributed to the continued marginalization of the CSKT on the Flathead Reservation, and by extension also of Indigenous Peoples in the western hemisphere. However, a series of U.S. Supreme Court cases set precedent for quantification of Tribal reserved water rights; the *Winters'* (see section 2.1.1) and *Winans* (see section 2.1.2) cases of 1908 and 1905, respectively, provided the foundation for the existence of quantifiable CSKT water rights under MT law. Over the past 50 years, tribes across the U.S. have asserted these rights in state water adjudications to obtain water rights for reservation purposes, as well as to keep water instream for aquatic habitat and culturally-significant species protection (Colby et al., 2005). Further, the existence of these rights provided the CSKT the ability to engage in a water rights negotiation and settlement process with the U.S. government and the State of Montana to potentially avoid future litigation or conflict over water on the Flathead Reservation.

The water rights journey for the CKST, federal government, and the State of Montana began in 1979 when the United States, on behalf of the Tribes, filed a lawsuit (*United States v. Abell*, No. CIV-79-33-M) in U.S. District Court for the District of Montana to establish a determination of the Tribe's respective water rights (Walker & Baker, 2013). Resulting from this litigation, the Montana Legislature established the Montana Reserved Water Rights Compact Commission (MRWRCC) in 1979 (Walker & Baker, 2013). The purpose of the RWRCC was to "conclude compacts for the equitable division apportionment of waters between the state and its people and the several Indian Tribes claiming reserved water rights within the state" (Walker & Baker, 2013; see also Montana Code Annotated (MCA) 85-2-702(1)).

After attempts failed to enact a CSKT-Montana Water Rights Compact in the 2013 Montana State Legislature, the 2015 Legislature ratified the Confederated Salish and Kootenai Water Compact (CSKT Compact, 2015). The water rights negotiated in the Compact are now codified as MT state law (85-20-1901, MCA). The Compact quantified water for: The Flathead Indian Irrigation Project (FIIP), existing uses by the Tribes, their members and allottees, direct flow rights from the Flathead River (Flathead System Compact Water), instream flow rights on the Flathead Reservation, minimum reservoir pool elevations in FIIP reservoirs, and contract rights to stored water held by MT FWP in Painted Rocks Reservoir (CSKT Compact, 2015). The Compact also recognizes all traditional, religious, and cultural uses of water by members of the CSKT within the State of Montana all-year-round (CSKT Compact, 2015). The Compact quantifies the Tribe's water rights for all time. This means the agreement recognizes and quantifies the CKST's instream flow rights on and off the Flathead Reservation in exchange for the Tribes' agreement to renounce all future water claims within the State of Montana (Tweeten, 2015). However, aspects of the Compact rely on federal funding and other compromises that need approval from the Tribes and federal parties (CSKT Compact, 2015). This is where the proposed CSKT Water Rights Settlement comes into play. The role of federal enactment of the CSKT Water Rights Settlement is to ratify and implement terms and conditions that are detailed in the Compact between the Tribes, the State of Montana, and the US Government. Further, the CSKT Water Settlement ensures that money is provided for Compact implementation, the rehabilitation of the FIIP system, and releases the subsequent liability of the U.S. for reserved tribal water rights (S. 3019, 2019) (see section 2.4.1).

On December 11, 2019, Senate Bill 3019 was introduced to the floor by Montana Senators Daines and Tester, entitled the "Montana Water Rights Protection Act" (S. 3019, 2019).

The purpose of the Act is to achieve a fair, equitable, and final settlement of claims of water rights in the State of Montana—to authorize and fund the Settlement companion of the CSKT Compact (see section 2.4.5). Since the introduction of S. 3019, the bill was referred to the Committee on Indian Affairs, but no further Congressional action has been taken on the bill (S. 3019 - Montana Water Rights Protection Act, 2019).

Problem Statement

The CSKT are waiting for a decision from the U.S. Congress on the enactment of the water rights settlement on which the CSKT-Montana state water rights Compact, codifying the Tribe's reserved water rights, is partially contingent. Given the recent difficulty of Congress to pass large spending bills related to natural resources, and especially the recent hesitancy to authorize and appropriate money for Indian Water Rights Settlements, there is a possibility that the necessary legislation will not be passed to authorize and fund the CSKT settlement in the near future. In the interim, the CSKT-Montana Compact that quantifies the CKST's reserved water rights could be enforced by the State of Montana and the Tribe without the additional funding from the Settlement to support necessary water delivery infrastructure improvements to the degraded Flathead Indian Irrigation Project (FIIP). Therefore, the purpose of this thesis research is to investigate a series of hydrologic scenarios by modeling the delivery of water to agricultural users on the Flathead Reservation, with and without planned infrastructure improvements. If legislation is not enacted authorizing the settlement, the FIIP will revert to delivering water under current infrastructure constraints based on priority date—the date which the land owner first extracted water to be put to beneficial use—which will also include previously unquantified tribal water rights now recognized in the Compact. Scenario modeling is a means to better understand how the CSKT Compact and potential federal legislation can impact irrigation water deliveries on the FIIP, as well as the underlying hydrology of the Lower Flathead River Basin. Figure 1.1 displays the study area of this project.

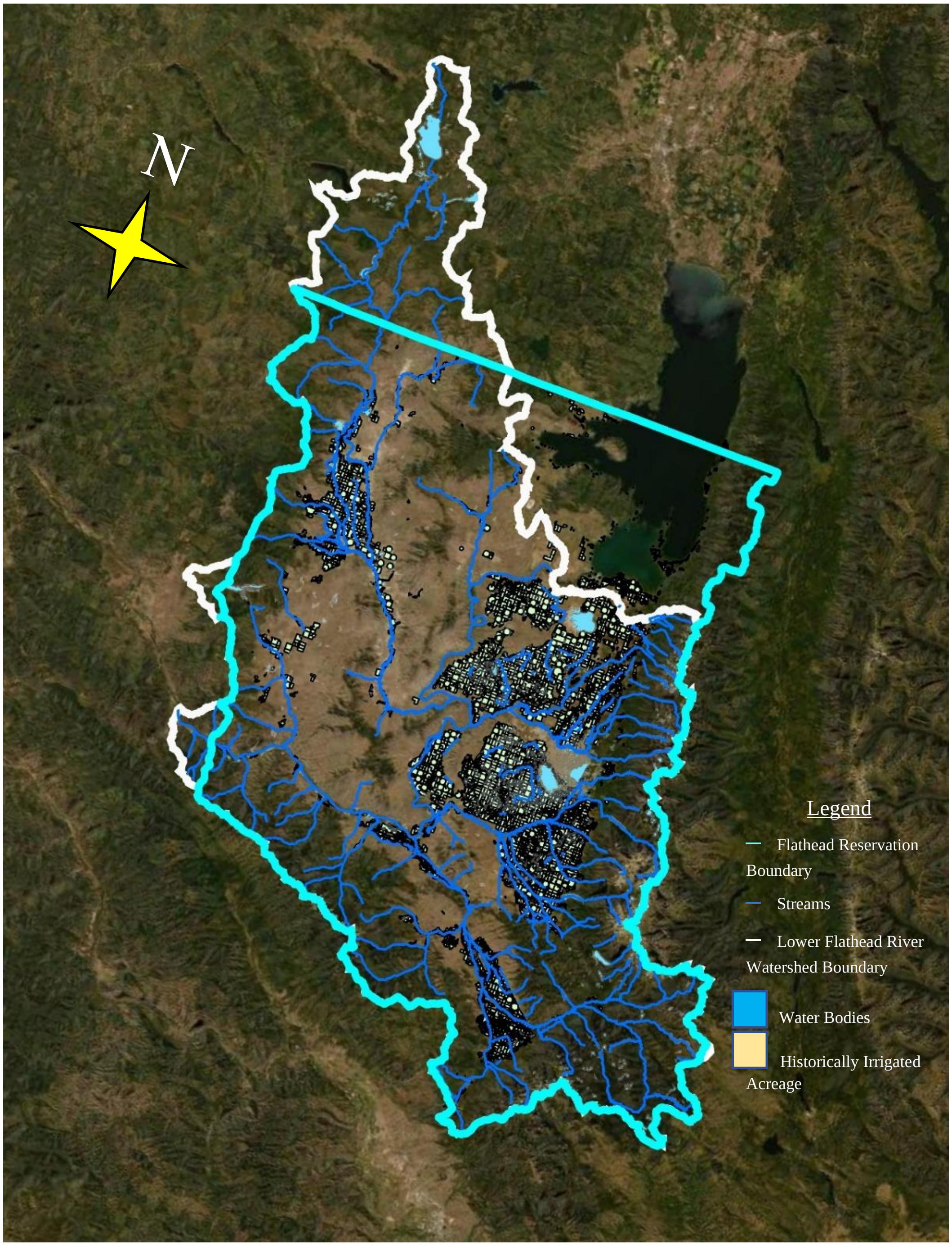

Figure 1.1 Study Site which shows the Lower Flathead River watershed (white line), Flathead Reservation (turquoise line), stream networks (blue line), water bodies (light blue polygons), and historically irrigated acreage in the FIIP influence area (beige polygons).

Research Questions

RQ1. Absent the enactment of the CSKT Settlement, how will the lack of FIIP infrastructure efficiency improvements (1) impact the hydrology of subbasins that both possess FIIP instream flow rights and irrigated agriculture, and (2) affect potential enforcement of tribal water rights?

> RQ1.1. Based on imposed climatic scenarios (i.e., dry, normal, wet years as determined in the CSKT compact), which subbasins are at risk of falling below Minimum Enforceable Instream Flows (MEFs) or Target Instream Flows (TIFs) set out in the CSKT Compact?
>
> RQ1.2. For subbasins that fall below MEFs and TIFs, how often and to what degree does this occur in modeled scenarios?

RQ2. If a call is made by the CSKT to enforce senior instream flow rights to ensure enough water is left instream for culturally-significant species habitat, how would the cessation of junior irrigation operations help meet FIIP instream flow rights?

In order to answer my research question, I used the Soil and Water Assessment tool. The Soil and Water Assessment Tool (SWAT) [https://swat.tamu.edu/] is a basin-scale, continuous-time model that operates on a daily time step and is designed to predict the impact of regional management on water in an ungauged watershed (Gassman et al., 2007). Further, in the context of this project, SWAT was a useful tool because I can impose water management input files (constraints) on modeled hydrologic balances for hydrologic response units (HRUs) of interest to the project and research questions. For this project I received the help of Dr. Raghavan Srinivasan, at Texas A&M University, who helped construct a baseline model in Hydrologic and Water Quality Systems (HAWQS) that uses SWAT as its core engine. With his aid, we constructed a calibrated Lower Flathead River watershed using 5 USGS gauge stations on the Flathead Reservation. Then, I simulated a consistently dry, wet, or normal hydrograph for comparison against a calibrated the SWAT model hydrograph in each subbasin to simulate how different the dry, normal, wet years (see section 3.5.1) would look compared to observed USGS data at the Flathead River at Perma, MT; I then compared these results to different modeled water management scenarios. The subbasins I modeled possess both a FIIP instream flow right and irrigated alfalfa or hay crop. From this, I was able to adjust the modeled values to analyze how changes in irrigation (e.g., alfalfa water demands, irrigation efficiency, no irrigation) in these different types of years might impact the amount of time that a streamflow would be in or out of compliance with minimum enforceable flows (MEFs) or target instream flows (TIFs) set out in the compact by the Tribe to protect streamflow and associated aquatic habitat and species. The scenarios constructed in this project will also model a dry, normal, and wet year where irrigation is occurring and not occurring. The ‘no irrigation’ scenario is designed to simulate a senior call on the Flathead River tributaries by the CSKT, and I wish to capture this scenario since it could be an option for the CSKT in the future. In this case, delivery of water would be based on priority date under Montana State law, which could explicitly include tribal rights because of the enactment of the CSKT-Montana Compact in 2015.

This all matters because without the funding contained in the Settlement Agreement to reconstruct the dilapidated (leaky) FIIP, there may not be enough water in the system to continue to provide for both irrigation and the enforceable thresholds of instream flow rights quantified in the CSKT Compact, especially given changing climate scenarios. Despite the clear quantification of water rights in the basin, new conflicts over water may arise. Modeling potential scenarios may provide inciteful information for the Tribes, State of Montana, and individual water users to consider when weighing options for managing water and asserting water rights moving forward.

In Chapter 2, I highlight major aspects of tribal water policy and law, the Tribal Nation – United States Watershed Adjudication Relationship, the history of the CSKT and the Flathead Reservation, and the details of the CSKT Water Rights Compact and Settlement. In Chapter 3, I explain my methods, specifically how I used SWAT and HAWQS, to answer my research questions, as well as the calibration outputs comparing this model against observed data from USGS gauging stations. In Chapter 4, I present outputs of modeled scenarios. In Chapter 5, I discuss key model interpretations pertaining to crop water stress, irrigation versus no irrigation, FIIP system efficiency, and implications for future hydrologic conditions (i.e., dry, normal, and wet years). In this chapter I also discuss assumptions made in modeling with SWAT, and the major limitations of this study. In Chapter 6, I conclude with recommendations from my findings, I offer takeaway messages for administering tribal water rights, and I highlight potential future research and modeling opportunities to continue this work.

CHAPTER 2. Background

In this chapter I describe the development of U.S.-tribal water law and policy, specifically as related to the federally-recognized Confederated Salish and Kootenai Tribes (CSKT) of the Flathead Reservation. The first section highlights the formative court cases and legislation of western US water law and policy in the context of quantifying water rights under the Doctrine of Prior Appropriation for federally-recognized Tribal Nations. The second section describes the relationship of the U.S. government in the adjudication of Tribal federally-reserved water rights. The third section covers the history of the CSKT and their connection to western Montana. The fourth and final section explains the distinction between the CSKT-Montana Water Compact and CSKT Water Settlement, the history of the Compact and Settlement, and the current status of each agreement and related legislation.

2.1 Tribal Water Policy and Law

2.1.1 History of Prior Appropriation for Tribal Nations in the Western United States

Most of the western United States (e.g., State of Montana) allocation of surface water operates under the doctrine of prior appropriation, which is the concept that the first people using water should have the first right to the water. Prior appropriation grants a water right to those who first appropriate surface waters, permitting priority access if the water is put to “beneficial use” (MCA 85-2-102). Later (junior) appropriators are entitled to divert only after the water is delivered to satisfy senior rights. The priority date of an appropriative right is the date the water is first used and determines who received water in times of shortage.

In 1908, the US Supreme Court confirmed a decision in the *Winters’ v. United States* case, which held that when reservations of land were established, enough water to fulfill the purposes of the reservations was implicitly reserved. Although colonialist, paternalistic, and racist, the stated purpose of creating Indian reservations at the time was to ‘further and advance the civilization and improvements of the Indians and to encourage habits of industry and thrift among them’ (*Winters v. United States*, 1908). This language created the foundation for the legal "purpose" of potential water rights associated with reservations. The priority date for these rights is the date the reservation was established via Treaty, Executive Order, or Act of Congress. In the case of Native American reservations, Winters rights retain their validity and seniority regardless of whether Tribal Nations put the water to beneficial use or not (*Winters v. United States*, 1908). The language and concept described in the *Winters* case were simple and brief, with no details on quantification, which left a legacy of legal uncertainty in the development of reserve water rights parameters for future ligation. This context of ambiguity sets the stage for varying and consistent interpretation in later cases about tribal reserved water rights (DesRosier, 2015).

In 1952, Congress passed the McCarren Amendment, which waived federal sovereign immunity and allowed states to bring the federal government into state-based general stream adjudications. It was a critical move given that states retained the power to adjudicate matters of quantity and allocation of private rights to use water. As some water sources in the West started to become ‘over appropriated’ (not enough to satisfy all uses), states began to undertake general stream adjudications, which are court proceedings to determine the type, amount, and priority date of every user’s water right in a particular watershed or basin (Colby et al., 2005). Later, the US Supreme Court ruled the McCarren Amendment also applied to state adjudications of Indian reserved water rights held in trust by the United States in the Colorado River Water Conservation District v. United States (*Colorado River Water Conservation District v. United States*, 1976)

(DesRosier, 2015). The matter of tribal water rights quantification and litigation should be an inherent matter of federal law and heard in federal court. However, under the 10th Amendment to the US Constitution, decisions over water rights were one of the powers left to individual states. The US was unwilling to consider state-based water rights at the federal level; therefore, the McCarren Amendment forced Tribal Nations to be joined in state court general stream adjudications because Congress waived federal sovereign immunity to participate in these proceedings at the state level (DesRosier, 2015).

It was not until the US Supreme Court decided the *Arizona v. California* case in 1963 that Native American tribes were considered legitimate parties to assert *Winters'* claims to water in the main stem of the Colorado River and some tributaries on Indian Reservations. The government, on behalf of five tribes in Arizona, California, and Nevada declared reserved tribal water rights existed on the Colorado River based on treaties and executive orders (*Arizona v. California*, 1963). The US Supreme Court decided the *Arizona v. California* court case, reaffirming the *Winters* doctrine and establishing the standard of practicably irrigable acreage (PIA) to quantify reserved water rights on the reservation set aside for agricultural purposes. This standard applies to all reservations, whether established by treaty, statute, or executive order. Under the PIA standard, Tribal Nations are legally entitled to the amount of water needed to irrigate all practicably irrigable acreage within their reservation boundaries. Moreover, waters quantified under the PIA standard may be used for any purpose and is not limited to agricultural purposed (Lemei, 2003).

The standard intends to account for relevant costs and benefits and to reflect the actual conditions of the reservation (Colby et al., 2005). Further, Tribal Nations can quantify their water right, identify source water, and establish a hierarchical list of water rights holder priority dates through either negotiated settlement or state water adjudication (DesRosier, 2015). An alternative route to water adjudication is to assert senior water claims in state court adjudication for the full amount, like in the Klamath Basin Adjudication (Klamath Basin Adjudication, 2014).

The quantification of federally reserved tribal water rights is a complex process requiring extensive hydrologic studies to determine the variability of flow in each stream, the optimal flows needed for fisheries and other aquatic resources of tribal significance, and a determination of the historical extent of the fisheries habitat and water use. Quantification also encompasses determining the flows necessary to preserve riparian areas to support traditional hunting and gathering on reservations. To substantiate these claims there is documentation through interviews with tribal members and historical analyses to establish the extent of hunting and gathering activities (Colby et al., 2005).

A critical Supreme Court case to note is the *United States v. New Mexico* (1978) case, which held that an examination of the limited purposes for which Congress authorized the creation of a national forest disproved the government's claim to water for recreation and wildlife purposes. The Court ruled that Congress created the national forest system to preserve water flows and the furnishing of timber (*United States v. New Mexico,* 1978*).* This case came about when the United States was diverting river water for domestic-residential use, road-water use, stock water use, and fish and wildlife purposed (*United States v. New Mexico,* 1978). The broadening of purposes for national forests occurred with the enactment of the Multiple-Use Sustained-Yield Act of 1960 (16 USCS § 528); however, it did not expand the reserved rights of the United States (*United States v. New Mexico*, 1978). Lastly, the Court held that the reserved rights doctrine was built on implication and were an exception to Congress' explicit deference to state water law in other areas. Therefore, Congress did not intend to enact the Multiple-Use

Sustained-Yield Act to reserved water for secondary purposes (*United States v. New Mexico,* 1978).

2.1.2 Tribal Off-Reservation Fishing and Hunting Rights

In 1905, the United States Supreme Court handed down *United States v. Winans,* which involved the interpretation of the Yakama Indian Nation's 1855 treaty with the United States (Goodman, 2000). The treaty reserved to the Tribe "the right of taking fish all usual and accustomed placed, in common with the citizens of the Territory, and of erecting temporary buildings for curing them" (Goodman, 2000). Two non-Indians (the Winans brothers) operated several state-licensed fish wheels near one of the Yakama Nation's usual and accustomed fishing places. They began excluding Yakama tribal members from the falls and destroyed their fish curing buildings. The United States brought the suit on behalf of the Yakama Nation to secure their right to access and use their usual and accustomed fishing sites (Goodman, 2000).

The US Supreme Court eventually ruled in favor of the Yakama Nation, and held that the right reserved through the 1855 treaty was more than a right of equal access to the fishery with non-Indians (which is what the trial court had held); instead, it was a servitude that burdened the non-Indian lands (Goodman, 2000). The Court articulated a foundational principle of Indian treaty interpretation: Indian treaties did not involve a grant of rights *to* the Indians, but were instead a grant *from* them, and therefore, reserved those rights not granted to the United States by the treaty (Goodman, 2000). The Court later held that these rights apply to reservations created through treaty, executive order, Congressional Act, or other legal instruments that reflect an agreement between the tribe and United States (Goodman, 2000).

Using Treaty language and this court precedent, many tribes have asserted rights to hunt, fish, trap, and gather on lands and waters that are outside the current boundaries of their reservations; this includes the CSKT (Goodman, 2000).

Another important case is the *United States v. Adair* case, argued in the District Court of Oregon. In 1975, the United States filed suit in federal court, "seeking a declaration of water rights within the Williamson River drainage" (Sudbury, 2004). Later in 1979, the District Court of Oregon ruled that the treaty guaranteed to the tribes an implied right to as much water on the reservation as necessary to protect their hunting and fishing rights, with a priority date immemorial (Sudbury, 2004). Sixteen years later, in 1999, the Oregon Water Resources Department belatedly announced the standard to use in quantifying the tribes' water right, stating that the tribes were entitled to the "minimum quantity of water necessary to protect treaty fish and wildlife resources as they existed in 1979" (Sudbury, 2004). This sparked a response from the US and Klamath Tribes to petition the District Court to exercise its continuing jurisdiction in order to clarify the legal standard in the *Adair I* and *II* cases. In *Adair III,* the court held that the tribes have a right to the allocation of water enough to fulfill the reservation's purpose, and this right must include enough water to support a productive habitat for fish (Sudbury, 2004). The ruling appeared to have created a right to water for habitat protection for treaty fisheries (Sudbury, 2004).

2.2 Tribal Nation – United States Watershed Adjudication Relationship

The role of the federal government in state-based watershed basin adjudications involving tribal nations is imperative due to treaty agreements (e.g., Hellgate Treaty of 1855) and the US' responsibility to advocate on behalf of tribal interests. The federal government's relationship to Tribal Nations can be viewed as a "trusteeship" or "guardianship." Tribal Nations are regarded as domestic dependent nations and have a ward-to-guardian relationship. The trust relationship provides federal protection for Indian natural resources and federal assistance in developing and managing resources. These resources include land, water, timber, and reservation fisheries. The United States' trust duty to Tribal Nations must be observed by any federal agency whose activities with the potential to affect the tribe's trust assets (Colby et al., 2005). In the case of state-based water rights negotiations (see discussion of the McCarren Amendment below), the federal government exercises its trust obligation by advocating for tribal water rights in state court proceedings and formal and informal negotiations.

2.3 Confederated Salish and Kootenai Tribes (CSKT)

2.3.1 History of the CSKT and the Flathead Reservation

The Flathead Reservation is home to three Tribes, the Bitterroot Salish, Upper Pend d'Oreille, and the Kootenai. Their aboriginal territories of these three Nations covered all western Montana and extended into parts of Idaho, British Columbia, and Wyoming. The subsistence patterns of the Nations developed over generations of observation, experimentation, and spiritual interaction with the natural world, creating a body of knowledge about the environment closely tied to seasons, locations, and biology. Their ways of life were iteratively infused with rich oral history and a spiritual tradition in which people respected the animals, plants, and other natural environmental elements. By learning from elders and passing knowledge to children, over time, their ways of life continue to this day (CSKT, 2020).

The Hellgate Treaty of 1855 established the Flathead Reservation; however, much of the Nation was taken out of Tribal ownership during land allotment that commenced in 1904. Further, the Dawes Severalty Act of 1887 (24 Stat. 388, ch. 119, 25 USCA 331, Acts of the 49th Congress, Second Session; enacted February 8, 1887) was extended to the Flathead Reservation through the 1904 Allotment Act (HR 12231, Public No. 159, 22 Stat. 302, 58th Congress, Second Session). The Dawes Act allowed lands previously protected in trust for Indians to by surveyed, assigned, and owned by individual Indians directly rather than in trust for the benefit as a whole. Once the land had been owned by an Indian for at least 2.5 years, the land could be permanently alienated by the Indian owner and transferred to third parties. The Dawes Act allowed the government to purchase land that had not been allotted to individual Indians and later gave those lands to non-Indians for settlement (Walker & Baker, 2013).

The 1904 Allotment Act mostly carved up the reservation lands for the settlement of non-Indians, which is now characterized as a "checkerboard" grid of CSKT and non-CSKT owned allotments (Walker & Baker, 2013). Resulting from these Acts, the CSKT now find themselves a minority on their reservation (Walker & Baker, 2013). This legacy has complicated the CSKT's quest to quantify its long-overdue right to water – and this history has set off a contentious debate over the quantification of tribal water rights on and off the Flathead Reservation.

2.4 CSKT Water Rights Compact and Settlement

2.4.1 History of the CSKT-Montana Water Compact

The water rights journey for the CKST, federal government, and the State of Montana began in 1979 when the United States, on behalf of the Tribes, filed a lawsuit (*United States v. Abell*, No. CIV-79-33-M) in US District Court for the District of Montana to establish a determination of the Tribe's respective water rights (Walker & Baker, 2013). The Montana Supreme Court ruled the State Legislature's implementation of the Water Use Act demonstrated Montana's consent "to Congress's grant of state jurisdiction over Indian reserved water rights" (Walker & Baker, 2013). Under this logic, the Montana water courts could exercise jurisdiction over the adjudication of tribal reserved water rights. The Montana Supreme Court also recognized the existence of tribal water rights and their superior water priority dates associated with the creation of a reservation (Walker & Baker, 2013).

Resulting from the federal litigation (*United States v. Abell*, No. CIV-79-33-M), the Montana Legislature established the Montana Reserved Water Rights Compact Commission (MRWRCC) under 85-2-702(1) MCA, chapter 697, Laws of Montana 1979 (Walker & Baker, 2013). The purpose of the RWRCC was to "conclude compacts for the equitable division apportionment of waters between the state and its people and the several Indian Tribes claiming reserved water rights within the state" (Walker & Baker, 2013). Further, the MRWRCC was commissioned to conclude compacts between the state and its people and the federal government claiming non-Indian reserved waters within the state (e.g., US Forest Service, National Park Service, etc.). The federal governments' ability to claim non-Indian reserved waters in the United States came to fruition in the *United States v. New Mexico* (see Section 2.1.1. for more information about the Supreme Court case) (*United Stated v. New Mexico*, 1978).

The CSKT water rights quantified in the Compact are composed of two parts: water rights that have a basis in Federal law and the other arising under state law. The proposed Compact also recognizes all traditional, religious, or cultural uses of water by members of the CSKT within the State of Montana all-year-round (CSKT Compact, 2015). The Compact also quantified water for: The Flathead Indian Irrigation Project (FIIP), existing uses by the Tribes, their members and allottees, direct flow rights from the Flathead River (Flathead System Compact Water), instream flow rights on the Flathead Reservation, minimum reservoir pool elevations in FIIP reservoirs, and contract rights to stored water held by MFWP in Painted Rocks Reservoir (CSKT Compact, 2015). Further, the CSKT Water Settlement ensures that all parties agree on the terms of the CSKT-Montana Compact, provides money for Compact implementation, and releases the subsequent liability for reserved tribal water rights (S. 3019, 2019).

The Tribes hold instream flow water rights for the: Kootenai River and Tributaries, Swan River, Lower Clark Fork River, and the North Fork of Placid Creek. Part of the Compact terms declares the CSKT as a co-owner of instream and public reservation water rights held by MWFP, and co-owners of water rights on Milltown Dam in the Upper Clark Fork (CSKT Compact, 2015). These off-reservation water rights were quantified for the maintenance of resources of cultural significance to the tribes, including wetlands, high mountain lakes, Flathead Lake, Boulder Creek Hydroelectric Project, Hellroaring Hydroelectric Project, wetlands appurtenant to lands owned by Montana Fish, Wildlife, and Parks (MFWP) and Department of Interior Fish and Wildlife Services (DOIFWS) (CSKT Compact, 2015). Lastly, these off-reservation water rights are prime examples for recognizing the CSKTs' *Winans* rights discussed in Section 2.1.2.

The Compact quantifies the Tribe's water rights for all time. This means the agreement recognizes and quantifies the CKST's instream flow rights on and off the Flathead Reservation in exchange for the Tribes' agreement to renounce all additional water claims within the State of Montana (Tweeten, 2015). Further, the Compact provides additional water from the Flathead River, Flathead Lake, and Hungry Horse Reservoir to meet tribal instream and consumptive water needs. The additional water also provides a process to lease portions of water for new development [on the reservation] (Tweeten, 2015). A significant attribute of the Compact is the recognition of existing tribal uses, which include traditional cultural and religious uses. Lastly, the legal agreement establishes a joint state-tribal board to administer water use on the Flathead Reservation under a Reservation-specific law (Tweeten, 2015).

The Compact also provides a call protection on non-irrigators, groundwater irrigators with flow rates less than or equal to 100 gallons per minute (GPM), irrigators within the FIIP influence area, water rights upstream of the Flathead Reservation, water rights on the little Bitterroot River outside the reservation boundary, and water rights arising under state law appurtenant to lands acquired by the Tribes (CSKT Compact, 2015).

The Compact puts in place a working mechanism that regulates the use of the Tribes' *Winters* water rights and identifies and explains different components of their rights. The Compact identifies who can use the water right, how non-use will not relinquish rights, describes the review of registered existing water uses, changes in the use of the water right, a new development of the right, and leasing of the Tribes' water right (CSKT Compact, 2015).

Since the founding of the MRWRCC in 1979, the Commission has produced four enacted tribal reserved water rights settlements in the State of Montana, which is highlighted in Table 2.1 (Stern, 2019).

Table 2.1. Congressionally Enacted Water Rights Settlements for Federally-Recognized Montana Tribal Nations

Tribal Nation	Year Settlement Enacted	Act of Congress	Public Law Number
Northern Cheyenne Tribe	1992	Northern Cheyenne Indian Reserved Water Rights Settlement Act of 1992	PL102-374
Chippewa Cree Tribe of Rocky Boy	1999	Chippewa Cree Tribes of the Rocky Boy's Reservation Indian Reserved Water Rights Settlement Act of 1999	PL 106-263

Crow Tribe	2010	Crow Tribe Water Rights Settlement Act of 2010	PL 111-291
Blackfeet Nation	2016	Blackfeet Water Rights Settlement Act	PL 114-322

The MRWRCC has approved and enacted seven water compacts with all federally-recognized tribes in the State of Montana, as emphasized in Table 2.2 (MT DNRC, 2020).

Table 2.2. Montana State Legislature Enacted Water Compacts with Federally-Recognized Tribal Nations

Tribal Nation	Year Compact Enacted	Act of Montana State Legislature	Montana Code Annotated Section
Assiniboine and Sioux Tribes of the Fort Peck Indian Reservation	1985	Assiniboine and Sioux Tribes of the Fort Peck Indian Reservation Compact	85-20-201 MCA
Northern Cheyenne Tribe	1991	Northern Cheyenne Tribe Compact	85-20-301 MCA
Chippewa Cree of Rocky Boy	1997	Chippewa Cree Tribes of the Rocky Boy's Indian Reservation Compact	85-20-601 MCA
Crow Tribe	1999	Crow Indian Reservation Compact	85-20-901 MCA
Gros Ventre and Assiniboine Tribes of the Fort Belknap Reservation	2001	Gros Ventre and Assiniboine Tribes of the Fort Belknap Reservation Compact	85-20-1001 MCA
Blackfeet Nation	2009	Blackfeet Tribe Compact	85-20-1501 MCA
Confederated Salish and Kootenai Tribes	2015	Confederated Salish and Kootenai Tribes of the Flathead Indian Reservation Compact	85-20-1901 MCA

After attempts to enact the CSKT-Montana Compact in the 2013 Montana State Legislature, the 2015 Legislature ratified the Compact (CSKT Compact, 2015). The water rights negotiated in the Compact are now codified as MT state law (85-20-1901, MCA). However, aspects of the Compact rely on federal funding and other compromises that need approval from the Tribes and federal parties (CSKT Compact, 2015).

The enactment of the proposed CSKT-Montana Compact is an avenue the federal government may pursue to uphold the Hellgate Treaty and other legal precedence (e.g., *Arizona v. California, Winters v. United,* McCarren Amendment), obligations. The Compact settles all water claims within the Flathead watershed, allocates federal funding for FIIP infrastructure revitalization, and establishes the Flathead Reservation Water Management Board to handle the permitting and enforcement of waters rights in the basin. Without Congressional enactment of the Compact, there is less opportunity to collectively negotiate terms for water rights holders in the Flathead Basin. Further, without Congressional action via CSKT Settlement enactment, it is uncertain how the new quantification and delivery under Compact conditions will operate.

The role of federal enactment of the CSKT water rights Settlement is to ratify and implement terms and conditions that are detailed in agreements and compacts between the Tribes, the State of Montana, and the US Government. A Compact Implementation Technical Team (CITT) was established by the CSKT to plan and advise the Project Operator on the implementation of the FIIP operational improvements, rehabilitation and betterment, and adaptive management (CITT, 2017); more information on the CITT is found in Section 2.4.3. If the Settlement is enacted by Congress, another role the government plays is to appropriate funds to carry out the mission of settlement legislation. A companion CSKT Settlement Agreement now awaits approval by federal parties through the US Congress and Tribal parties through a vote of the CSKT tribal membership (MT DNRC, 2018). For the federal process, Senate Bill 3013 was introduced to the United States Senate floor on May 26, 2016, by Montana Senator Jon Tester (D-MT), then was referred to the Senate Committee on Indian Affairs for consideration on June 29, 2016. No further Congressional action was taken on S. 3013; however, a revival bill was introduced in 2019 aimed at enacting the CSKT-Montana Compact.

2.4.2 CSKT Efforts in CSKT-Montana Compact Negotiation

Starting in 1982, the CSKT embarked on a deliberative process to collect hydrologic data and technical information concerning Flathead Reservation water resources. Through this effort, the CSKT has developed a thirty+ year dataset, oftentimes on small and generally overlooked water resources, and has developed an in-depth understanding of surface and groundwater resources and their interactions (Makepeace & Metesh, 2015). The CSKT recognized the complexity of water use on the Flathead Reservation and the challenges of interjecting unquantified rights into already overutilized waters, so the CSKT has consistently sought into their negotiation efforts to apply a forward-looking and scientific approach to water allocation. Rigorously developed water budgets for natural and modified hydrology form the base level for this perspective, and the Tribes have applied the HYDROSS allocation model as the engine to hold and distribute water budget terms across the Jocko, Mission, and Little Bitterroot Valleys. These valleys are highly modified by irrigated agricultural served by the FIIP (Makepeace & Metesh, 2015). Prior to and concurrent with modeling work, major water budget terms (e.g., natural and modified hydrology, crop types and crop water consumption, irrigated acreage, and irrigation project infrastructure), were developed as stand-alone work products and inputs to the modeling framework (Makepeace & Metesh, 2015).

A limitation to the water claims made by the CSKT prior to Compact enactment was that claims were generally based on a Treaty-Era environment. Claims were developed without consideration for existing uses of water, which maximized claims. Lastly, the claims process did not consider the future administration of water, adaptive management, and damages contributions (Makepeace & Metesh, 2015).

Three main pillars of perspective were taken on behalf of the CSKT during water rights negotiations. Firstly, compact negotiations were based on current patterns of water use. Secondly, tribal water rights were developed with perspective to maintain existing uses. Lastly, negotiations should consider future administration of water, adaptive management, and damages contributions (Makepeace & Metesh, 2015).

2.4.3 CSKT-Montana Compact Implementation Technical Team (CITT)

The CSKT-Montana CITT was created to initially focus on developing recommendations to the CSKT, State of Montana, and the United States (Compact Parties) on the use of available funding for water measurement, a stock-water program, and an on-farm efficiency program (CITT, 2017). The CITT is responsible for the allocation of water between instream and irrigation uses based on the projected and realized annual water supply (see Appendix 3.5 of Compact) (CSKT, 2015). The Compact Parties agree that the CITT may adjust allocations throughout the irrigation season, based on water supply, seasonal climate variability, and irrigation management considerations to comply with the MEFs, TIFs, and RDAs in its allocation of water (CSKT Compact, 2015).

2.4.4 CSKT-Montana Water Right Priority Dates

The Compact quantified and codified in Montana State law off-reservation instream fisheries flow rights in the mainstem of the Kootenai River (Water Right No. 76D 30063810), the Swan River (Water Right No. 76K 30063809), and Lower Clark Fork River (Water Right No. 76N 30063808), respectively (see Appendices 24, 25, and 26 for general abstract of each water right) (CSKT Compact, 2015). The priority date attached to these rights is time immemorial (CSKT Compact, 2015).

The Compact also quantified and codified water used for sprinkler and flood irrigation, and by extension stock water, wetlands, and lawn and gardens, in the Flathead River basin, below Flathead Lake. FIIP irrigation water use has an enforceable priority date of July 16, 1855, at 12 A.M. The Compact appropriates water from the Flathead River, below Flathead Lake, and from tributaries to the Jocko River (Water Right No. 76L 30052931), the Clark Fork River, below the Flathead River (Water Right No. 76L 30052930), and the Blackfoot River (Water Right No. 76L 30052932), for use in the FIIP administrative areas (see Appendix 5 for general abstracts and maps of each water rights for FIIP water use rights) (CSKT Compact, 2015).

2.4.5 CSKT Water Rights Settlement

On December 11, 2019, US Senate Bill 3019 was introduced to the floor by Montana Senators Daines and Testers, entitled the "Montana Water Rights Protection Act" (S. 3019, 2019). The purpose of the Act is to achieve a fair, equitable, and final settlement of claims of water rights in the State of Montana. Further, the Act aims to authorize, ratify, and confirm the water rights compact entered by the Tribes and the State, to the extent that the Compact is consistent with this Act (S. 3019, 2019). Regarding irrigation activities, in Section 7 of the proposed bill, the Tribes are able to carry out the following three activities relating to the FIIP, in coordination with the US Bureau of Indian Affairs (BIA): (1) rehabilitation and modernization, (2) mitigation, reclamation, and restoration, and (3) acquisition of interests (S. 3019, 2019).

Firstly, the bill calls for the rehabilitation of structures, canals, and pumping facilities, including dam safety improvements; irrigation facility upgrades that improve water management and operational control at irrigation diversion works; irrigation facility upgrades to reduce losses in the conveyance of water from irrigation sources of supply to irrigation points of use, planning, design, and construction of additional pumping facilities; operational improvements to infrastructure within the distribution network of the FIIP; and reconstruction, replacement, and automation at irrigation diversion works, linking of open canals, and placement of open canals in pipes (S. 3019, 2019). Secondly, the Act allows for the Tribes to mitigate, reclaim, and restore streams, wetlands, banks, slopes, and waste ways within, appurtenant to, or affected by the FIIP. Thirdly, the bill enables the Tribes to acquire easements or other interests in real property necessary to carry out any activity under this section, and the land would then be held in trust by the United States for the benefit of the Tribes (S. 3019, 2019).

The bill also establishes an agreement between the Tribes and the Secretary of Interior (Secretary) for cooperative operation and management of the FIIP system (S. 3019, 2019).

An important component of S. 3019 is the formation of the Séliš-Qlispé Ksanka (SKQ) Settlement trust fund (Trust Fund) in Section 8, which is to be managed, invested, and distributed by the Secretary, and to remain available until expended, consisting of the amounts deposited in the Trust Fund under Section 9, together with any interest earned on those amounts, for the purpose of carrying out this Act. In Section 9, the Act appropriates to the Secretary and amount of $1,900,000,000 for deposit in the Trust Fund (S. 3019, 2019).

Lastly, the bill waives and releases all Tribal water claims and future claims against the United States, which then can be enforced on the date the Secretary publishes in the Federal Registrar a statement. The statement must include findings that:

1. The Montana Water Court has approved the Compact in a manner from which no further appeal may be taken;
2. If the Montana Water Court is found to lack jurisdiction, the applicable US district court has approved the Compact as a consent decree from which no further appeal may be taken;
3. All amounts authorized to be appropriated under Section 9 has been approved;
4. The Tribes have ratified the Compact;
5. The Secretary has fulfilled the requirements of Section 6; and
6. The waivers and releases have been executed by the Tribes and the Secretary (S. 3019, 2019).

According to the bill sponsor, Senator Steve Daines, the Montana Water Rights Protection Act "is a good-faith compromise that will bring final resolution to a century-long water dispute, avoid years of costly litigation, and save taxpayers over $400 million" (Daines, 2019). Bill co-sponsor, Senator Jon Tester, states, "This bill will help bring years of uncertainty for the [CSKT], taxpayers, farmers, and ranchers to an end" (Daines, 2019).

2.4.6 Other Issues the CSKT-Montana Compact Decides

The proposed 2015 CSKT-Montana Compact came to fruition through decades of negotiations between the Tribes, MT, and the United States. The Compact was included in a proposed water rights Settlement that will quantify (or adjudicate) water allocations for the CSKT on and off the Flathead Reservation (Tweeten, 2015). Further, the Settlement also sets in place a Unitary Administration and Management Ordinance that provides for management of water rights on the Flathead Reservation. For the CSKT, the Compact would protect valid existing water uses decreed by the Montana Water Court (MWC) or permitted by the DNRC, provide legal protection for domestic wells and permits established after 1996 that are currently not legally permitted on the Flathead Reservation, and establish a process to permit new water uses on the reservation (e.g., domestic, stock, wetlands, municipal, hydropower, industrial, commercial, and agriculture). The Compact recognizes the jurisdiction of the Flathead Reservation Water Management Board over water rights, including permitting of new uses, changes of existing uses, enforcement of water right calls, and all aspects of the enforcement within the boundaries of the Flathead Reservation (CSKT Compact, 2015). Moreover, the Compact provides a process for making changes to existing water uses, supplies funding for improved water measurement, water supply forecasting, habitat, and FIIP improvements (Tweeten, 2015).

2.4.7 Current Status of Settlement Legislation

On December 11, 2019, S. 3019 was read twice by the US Senate and has been referred to the Committee on Indian Affairs. No further Congressional action has been taken on the bill (S. 3019 - Montana Water Rights Protection Act, 2019).

CHAPTER 3. Methods

3.1 Soil and Water Assessment Tool (SWAT)

The Soil and Water Assessment Tool (SWAT) [https://swat.tamu.edu/] is a basin-scale, continuous-time model that operates on a daily time step and is designed to predict the impact of regional management on water in an ungauged watershed (Gassman et al., 2007). Further, in the context of this project, SWAT is a useful tool because I can impose water management input files (constraints) on modeled hydrologic balances for hydrologic response units (HRUs) of interest to the project and research questions. SWAT is a prime modeling engine for use in this project because it allows for the input of both watershed management and hydrologic process parameters to influence the scenarios that I model to address my research questions. Further, the ability to alter streamflow input data to model Compact-derived hydrologic scenarios (e.g., wet, dry, and normal flow years), along with general irrigation operations, was a large factor in selecting SWAT as my project model engine. Lastly, SWAT allows users to manipulate irrigation infrastructure efficiency parameters, which allows me to investigate the productivity of the FIIP system as is, and if/when the CSKT Compact and Settlement are fully enacted.

Generally, SWAT is widely used in assessing soil erosion prevention and control, non-point source pollution control, and regional management in watersheds (USDA ARS Grassland Soil and Water Research Laboratory & Texas A&M AgriLife Research, 2018). Users can download various versions of SWAT software, as well as data tools that are compatible with highly used modeling programs. Software and data tools include: QSWAT, SWAT-MODFLOW, SWAT+, ArcSWAT, SWAT-CUP, etc. (USDA ARS Grassland Soil and Water Research Laboratory & Texas A&M AgriLife Research, 2018). For this thesis project, I identified ArcSWAT as a useful tool to begin exploring how to answer my research questions.

3.2 ArcSWAT

To address the proposed research questions, I employed the ArcGIS version of the Soil and Water Assessment Tool (ArcSWAT) to create model scenarios outputting the conveyance of water throughout all irrigation service areas of the Flathead Indian Irrigation Project (FIIP). ArcSWAT is physically based, computationally efficient, and capable of continuous simulations over long time periods, and remote sensing based (ArcSWAT, 2020). Specifically, I constructed two primary scenarios that mimic under two potential policy regimes: a baseline pre-Compact enacted scenario and Compact-enforced water allocations scenario on the CSKT reservation. Geospatial data pertaining to FIIP service areas and historically irrigated acreage were obtained from the CSKT Department of Natural Resources, with consent.

3.2.1 ArcSWAT Input Data

Primary SWAT data inputs include weather, elevation, soil temperature and properties, and land management (Gassman et al., 2007) (ArcSWAT, 2020); much of the input data required is publicly available and can be found in Table 3.1.

Table 3.1 Data Inputs for ArcSWAT Model Construction

Input	**Source**	**Notes**
Weather	National Centers for Environmental Protection (NCEP) Climate Forecast System Reanalysis (USDA ARS Grassland Soil and Water Research Laboratory & Texas A&M AgriLife Research, 2018)	1979 – 2014

Elevation	*National Elevation Dataset (NED)* (USGS, 2020)	30-meter digital elevation model (DEM)
Soil Properties	*USDA-NRCS* (USDA-NRSC, STATSGO2, 2018)	STATSGO2
Land Use	*Multi-Resolution Land Characteristics Consortium (MACL)* (Fry et al., 2011)	NLCD (2006) and Cropland Data Layer (CDL) (2011-2012)

The following weather input data were used for model simulations: daily precipitation (mm), maximum/minimum air temperature (deg C), solar radiation (MJ/m^2), wind speed (m/s) and relative humidity (fraction). Weather data for the Flathead Reservation were obtained from the National Centers for Environmental Protection (NCEP) Climate Forecast System Reanalysis, which was completed over a 36-year period from January 1, 1979, to July 31, 2014 (USDA ARS Grassland Soil and Water Research Laboratory & Texas A&M AgriLife Research, 2018). The following north latitude, east longitude, south latitude, and west longitude coordinates constrained the area in which weather station information was obtained: N Latitude = 47.8708; E Longitude = -113.6553; S Latitude = 47.0407; W Longitude = -114 8473 (USDA ARS Grassland Soil and Water Research Laboratory & Texas A&M AgriLife Research, 2018). Within the confines of the coordinates, eight weather stations were identified and used as input weather data into the ArcSWAT model (USDA ARS Grassland Soil and Water Research Laboratory & Texas A&M AgriLife Research, 2018).

In order to construct a delineated watershed, elevation, land cover, and soil data were required inputs to ArcSWAT (ArcSWAT, 2020). Elevation seamless raster data for the Flathead Reservation was obtained from the National Elevation Dataset (NED), product assembled by the U.S. Geological Survey at [https://www.ned.usgs.gov] (USGS, 2020). Three separate seamless raster files were obtained from the NED and merged together into one raster using the *Mosaic to New Raster* tool in ArcMap (ESRI, 2017). Land cover data were gathered from the National Land Cover Database (NLCD) at [https://www.mrlc.gov/], which was produced through a cooperative project conducted by the Multi-Resolution Land Characteristics (MRLC) Consortium (MRLC Consortium, 2011). The 2011 NLCD was used instead of the NLCD 2016 because, at the time of watershed delineation, the 2011 version was the most recent. Lastly, soil data was derived from the Digital General Soil Map of the United States (STATSGO2), which was created by the U.S. Department of Agriculture (USDA) Natural Resources Conservation Services (NRCS) (USDA-NRCS, STATSGO, 2018). Soil data exported from the NRCS Web Soil Survey (USDA-NRCS, Web Soil Survey, 2019) was delivered in the Soil Survey Geographic Database (SSURGO) format (USDA-NRCS, SSURGO, 2018). HRUs, in this case,

3.2.2 Creating HRUs in ArcSWAT

In SWAT, a watershed is divided into multiple subwatersheds, which are then further subdivided into HRUs that consist of homogeneous, unique, land use, management, soil characteristic attributes (Gassman et al., 2007) (Arnold et al., 2012). The HRUs represent percentages of the subwatershed area and are identified spatially within a SWAT simulation. Alternatively, a watershed can be subdivided into only subwatersheds that are characterized by dominant land use, soil type, and management (Gassman et al., 2007). Simultaneously, HRUs simulate irrigation water flows between surface runoff and infiltration (Gassman et al., 2007). HRUs were incorporated into SWAT as part of the Hydrologic Unit Model for the United States (HUMUS) (Arnold et al., 2012). For geospatial projection, we selected the NAD1983 UTM Zone 11N Projection, which is bounded by -120°W and -114°W longitudes and covers most of the Flathead Reservation (Butler et al., 2007). After inputting land use, soil type, and elevation data, I defined threshold percentage values to construct multiple HRUs for future analysis. In this case, the HRU definition threshold values were set at 20% land-use type, 10% soil type, and 20% slope. These values are considered adequate as a default setting for most applications (Arnold et al., 2012). The land use threshold level is used to eliminate minor land uses in each subbasin. Land uses that cover a percentage (or area) of the subbasin less than the threshold level are eliminated. After the elimination process, the area of the remaining land uses is reapportioned so that 100% of the land-use area in the subbasin is modeled (Arnold et al., 2012). The soil threshold controls the creation of additional HRUs based on the distribution of the selected land uses over different soil types. This scale is used to eliminate minor soil types within the land-use area. Once minor soil types are eliminated, the area of remaining soils is reapportioned so that 100% of the land-use area is modeled (Arnold et al., 2012). The slope threshold influences the creation of additional HRUs based on the distribution of the selected soil types over different slope classes (a range between 0 and 1). This scale is used to aggregate slope classes within a soil on a specific land-use area. Once minor slope classes are eliminated, the area of remaining slope classes is reapportioned so that 100% of the soil area is modeled (Arnold et al., 2012).

Analyzing the majority land-use and soil type of modeled historically irrigated acreage (HIA), by the Confederated Salish and Kootenai Tribes (CSKT) Natural Resources Department, was of interest for this project. The modeled HIA was presented as polygon shapefiles (CSKT Natural Resources, 2019). Using the *Zonal Statistics as Table* tool (ArcToolbox → Zonal → Zonal Statistics as Table), I created two geodatabase raster datasets displaying the majority land-use type for each HIA polygon and majority soil type for each HIA polygon, respectively—to create a set of unique HRUs that indicate irrigated parcels of dominant land use and soil types.

Following many attempts to calibrate the constructed ArcSWAT model against observed flow values in the Flathead Valley, I was introduced to the Hydrologic and Water Quality Systems (HAWQS) online modeling platform as an alternate method for creating a baseline model of the FIIP system as currently operated. HAWQS is pre-calibrated and could allow for faster and more efficient development and modeling of scenarios through the online interface coupled with the SWAT Editor program.

3.3 Hydrologic and Water Quality Systems (HAWQS)

The HAWQS is a web-based interactive water quantity and quality modeling system that employs SWAT as its core modeling engine. HAWQS provides users with interactive web interfaces and maps, pre-loaded input data (Table 3.2), and outputs that include tables, charts, and raw output data (Texas A&M University Spatial Sciences Laboratory, 2017). I opted to use HAWQS because of the enhanced usability of a SWAT interface, the ability to model the Lower Flathead River watershed on the Flathead Reservation, convenience of pre-loaded and pre-calibrated input data that was exceedingly challenging to calibrate in the ArcSWAT interface. Further, I utilized HAWQS because it can easily simulate the effects of changes in watershed management practices based on an extensive array of crops, soils, natural vegetation types, and land use (Texas A&M University Spatial Sciences Laboratory, 2017). This ability simplified aggregation of CSKT Water Rights and Compact quantifications found in the appendices of the Compact for inclusion as data suitable for input to SWAT Editor to model climatic and management scenarios of interest.

HAWQS users can select from three watershed scales, or hydrologic unit codes (HUCs) – 8-digit (~1813 km^2), 10-digit (~588 km^2), 12-digit (~104 km^2) – to run simulations. A key, helpful feature of HAWQS is that the systems allow for further accumulation and scalability of daily, monthly, and annual estimates of water quality across large geographic areas up to and including the continental United States (Texas A&M University Spatial Sciences Laboratory, 2017). Table 3.2 highlights the sources of data inputted to the HAWQS for simulations.

Table 3.2 Input Data Sources for HAWQS

Input	**Source**	**Notes from Publisher**
Weather	1. *National Climatic Data Center (NCDC) National Weather Service (NWS)/National Oceanic and Atmospheric Administration (NOAA)* (Menne et al., 2012) 2. *Parameter-elevation Regressions on Independent Slopes Model (PRISM)* (PRISM Climate Group, 2016) 3. *Next Generation Radar (NEXRAD)* (NOAA NWS, 1991) 4. *NEXRAD PRISM* corrected	1. 1961 – 2010 (Theissen Polygon) 2. 1981 – 2015 (gridded) 3. 2005 – 2015 (gridded) 4. 2005 – 2015 (gridded)
Soil	*USDA-NRCS* (USDA-NRSC, STATSGO2, 2018)	STATSGO2
Land Use	*Multi-Resolution Land Characteristics Consortium (MACL)* (Fry et al., 2011)	NLCD (2006) and Cropland Data Layer (CDL) (2011-2012)
Aerial Deposition	*National Atmospheric Deposition (NADP)* (PRISM Climate Group, 2016)	(1980 – 2010) monthly

Watershed Boundaries	*USGS* (USDA-NRCS, USGS & EPA, 2019)	HUCs 8, 10, and 12
Stream Networks	*National Hydrography Dataset (NHDPlus)* (EPA & USGS, 2019)	Reduced form
Elevation	*National Elevation Dataset (NED)* (USGS, 2020)	30-meter digital elevation model (DEM)
Point Sources	*USGS* (Schwarz, 2006)	Regression of population and SPARROW model outputs
Management Data	*USDA* (USDA-NASS, 2020) & (White et al., 2016)	CDL (tillage, fertilizer/manure, crop yields) (NLCD field database) and Cropland Management Dataset
Reservoirs	*U.S. Army Corps of Engineers* (USACE, 2018)	National Inventory of Dams
Livestock and Crops	*USDA – National Agricultural Statistics Service (NASS)* (USDA-NASS, 2020)	
Model	*USDA – Agriculture Research Service and Texas A&M University* (Arnold et al., 2012)	Soil and Water Assessment Tool

3.3.1 Delimiting a modeled area in HAWQS

To create a project in HAWQS, a user must create an online account in the HAWQS interface to access the programs [https://hawqs.tamu.edu/]. Once an account has been created and the user logged in, 'Create a new project.' Once a project has been created, click on the ‘Set HRUs’ button to create hydrologic response units within each HUC 12 captured in the project watershed. Three options to set percentage thresholds for land use type, soil type, and slope class are presented for the user to create—like the manual process in ArcSWAT, only with a streamlined interface. In this case, the thresholds set for each classification was 1 km^2 land-use type, 1 km^2 soil type, and 1 km^2 slope class. This was to eliminate minor land uses, soils, and slopes in each subbasin, and so that the project can be managed more efficiently (R. Srinivasan, personal communication, May 8, 2020). In other words, land uses, soils or slopes that cover an area less than the 1 km^2 were eliminated.

HAWQS then creates new HRUs; the HAWQS interface makes it easy to define and change HRUs at any time. HAWQS provides a table describing the redistribution of the area by land use, soil type, and slope class, along with pie charts showing the distribution of land use in the modeled area with (Figure 3.1) and without (Figure 3.2) the manual threshold applied. The total area in all subbasins devoted to growing alfalfa and hay is 329.82 km^2 and 324.78 km^2, respectively. After applying a land-use threshold, the area growing alfalfa decreased to 327.71 km^2, and hay increased to 326.12 km^2, respectively. This is because if an area growing hay and alfalfa in each subbasin (n=57) was less than 1 km^2, that land use type was not captured in the threshold applied HRUs, and therefore eliminated. Examples of these land-use types that fall in the 'Others under 1% each' category include: 'wetlands-forested', 'spring wheat', 'winter wheat',

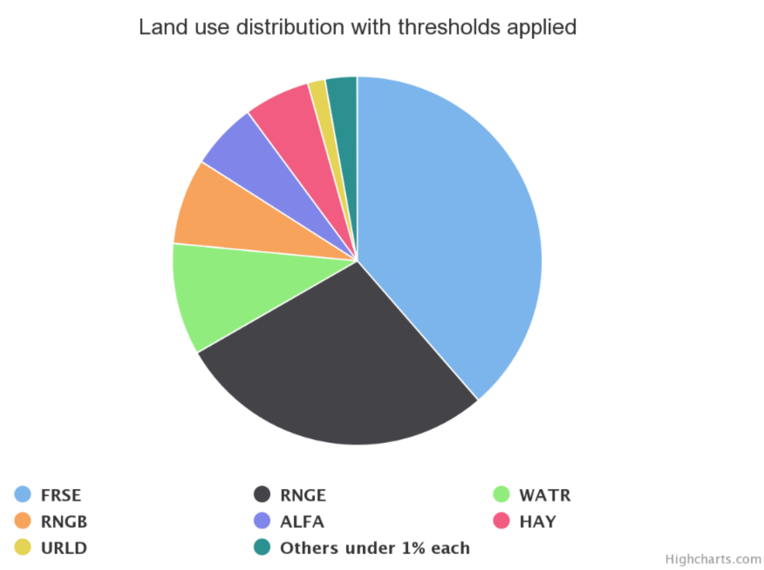

Figure 3.1 Proportion of land use type distributed across the modeled watershed with a 1 km^2 HRU threshold applied. Note: FRSE is 'forest-evergreen', RNGE is 'range-grasses', WATR is 'water', RNGB is 'range-bush', ALFA is 'alfalfa', HAY is 'hay', URLD is 'residential-low density'. 'Others under 1% each' at land-use types still above the 1 km^2 threshold, but each makes up less than 1% of the total land-use area of the modeled watershed.

‘corn’, etc. Once the HRUs were construction, I created a new project on the main HAWQS page. I was satisfied with the threshold applied HRU areas because minor land uses were not eliminated, even if the land use type was alfalfa.

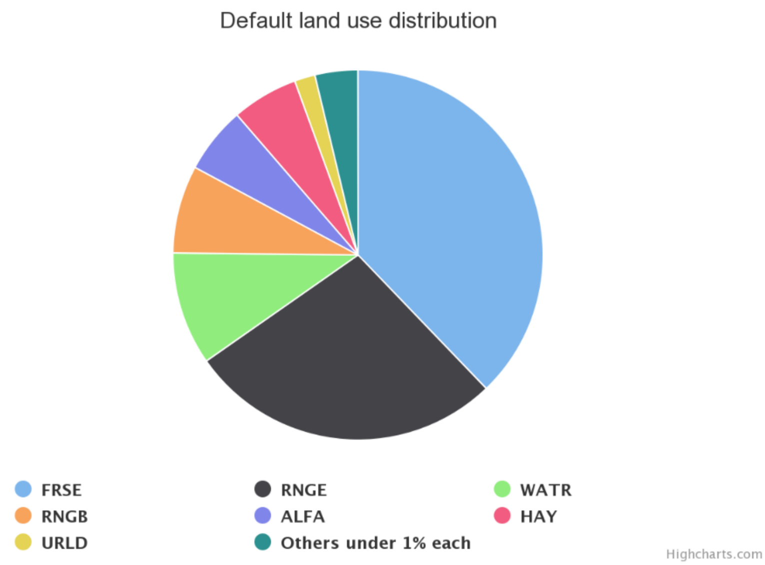

Figure 3.2 Proportion of land use type distributed across the modeled watershed with a 1 km^2 HRU threshold applied. Note: FRSE is 'forest-evergreen', RNGE is 'range-grasses', WATR is 'water', RNGB is 'range-bush', ALFA is 'alfalfa', HAY is 'hay', URLD is 'residential-low density'. 'Others under 1% each' at land-use types still above the 1 km^2 threshold, but each makes up less than 1% of the total land-use area of the modeled watershed.

After the HRUs were constructed, I created a baseline scenario that constructs a baseline delineated watershed and sets environmental parameters the scenarios will run under. This will allow users to customize SWAT input variables and run the model. The program also permits users to create multiple scenarios and make side-by-side comparisons (HAWQS, 2020). The process for running HAWQS is as follows: create a unique name for a scenario, select the weather dataset to use (in this project it is PRISM), the simulation's start and end dates (i.e., January 1, 1981, to December 31, 2018), the number of warm-up years (i.e., two years), SWAT output print type (i.e., monthly), and SWAT model version (i.e., SWAT 2102 rev. 670).

Once the scenario settings have been selected, a list of SWAT input data sources is presented that can be customized. Sections include: General watershed inputs and databases (i.e., basin input data, fertilizer input data, nutrient efficiency, etc.), weather data (i.e., climate scenarios, climate sensitivity, etc.), subbasin inputs (i.e., curve number, pothole variables, etc.), and agricultural management/best management practices/conservations practices (i.e., general parameters, operations management) (HAWQS, 2020). There is also the option to choose which reach, subbasin, and HRU variables and which HRUs to output. Once that is complete, a user can run the SWAT model in HAWQS. In the ‘Run Scenario Tasks’ table at the bottom of the page, click on the options available: Write SWAT input files, Write SWAT editor tables, Run SWAT 2012 rev. 670, Process SWAT output files, and to receive an email once is it all processed. Once the options have been chosen, click on the ‘Run selected tasks’ to run the SWAT project scenario. Output tables are available in the project folder from the main HAWQS page (HAWQS, 2020).

3.4 SWAT-CUP (Calibration and Uncertainty Programs)

SWAT-CUP is a program for the calibration of SWAT models. The program is used to perform calibration, validation, sensitivity analysis, and uncertainty analyses (Eawag Aquatic Research, 2015). The software series links SUFI-2, GLUE, ParasSol, MCMC, and PSO (see below for descriptions) to SWAT. SWAT-CUP was created by Eawag, a Swiss Federal Institute that investigates the prediction ambiguity of the parent SWAT model (Khatun et al., 2018). The factors for prediction ambiguity can be chosen in accordance with the objectives of the study. Within the SWAT-CUP interface, model calibration and comprehensive sensitivity analysis can be coupled with the SWAT model (Khatun et al., 2018). This is achieved by applying diverse variables that include water content, pressure head, and cumulative outflow on the estimation of hydraulic parameters (Abbaspour et al., 1999) (Khatun et al., 2018). The SUFI-2 algorithm was used for calibration of the SWAT model and sensitivity analysis. SUFI-2 is a multisite and semi-automated global search procedure (Khatun et al., 2018).

3.4.1 Sequential Uncertainties Fitting Vers-2 (SUFI-2) Algorithm

In SUFI-2, the degree to which all uncertainties are accounted for is quantified by a measure referred to as the P-factor. The P-factor is the percentage of measured data bracketed by the 95% prediction uncertainty (95PPU) (Khalid et al., 2016). An additional measure of qualifying the strength of a calibration and uncertainty analysis is the R-factor, which is the average thickness of the 95PPU band divided by the standard deviation of the measured data (Khalid et al., 2016). SUFI-2 aims to bracket most of the measured data with the smallest possible uncertainty band. The 95PPU is calculated at the 2.5% and 97.5% levels of the cumulative distribution of an output variable obtained through Latin hypercube sampling, disallowing 5% of the very bad simulations (Khalid et al., 2016). The value of the P-factor ranges from 0 to 100%, while that of the R-factor ranges between 0 and infinity, respectively (Khalid et al., 2016). For example, a P-factor of 1 and R-factor of zero is a simulation that exactly corresponds to the measured data (Khalid et al., 2016).

In the SUFI-2 algorithm, the assessment of the sensitivity parameters is measured using the t-stat values, where the values are more sensitive for a large in absolute t-stat values. A t-stat value is the coefficient of a parameter divided by its standard error. It is a measure of the precision with which the regression coefficient is measured (Abbaspour, 2015). For example, if a coefficient is "large" compared to its standard error, then it is likely not equal to zero; thus, the parameter is sensitive (Abbaspour, 2015). P-values are used to determine the significance of the sensitivity where the parameters become significant if the P-value is close to zero (Khalid et al., 2016). The local sensitivity analysis or one-at-a-time sensitivity shows the sensitivity of a variable to the changes in the parameter if all other parameters are kept constant at some value (Khalid et al., 2016).

3.4.2 Important steps in the Verification, Calibration, and Validation of HAWQS model

Verification of the HAWQS model occurs in the program SWAT Check (Ver. 1.2.0.10). The intended purpose of SWAT Check is to identify model problems early in the modeling process (SWAT Check, 2018). Further, the program is designed to compare a variety of SWAT outputs to nominal ranges based on the judgment of model developers (SWAT Check, 2018).

Calibration and Validation occur in SWAT-CUP. For project simulations, HAWQS produced SWAT-CUP output files, which included simulated flow data and diversion information for crop irrigation. Within SWAT-CUP, 70 parameters pertaining to input files for groundwater (.gw), HRUs (.hru), management (.mgt), soil properties (.sol), etc., are designed to be systematically changed to optimize parameters of the modeled watershed (Eawag Aquatic Research, 2015). Examples of parameters include soil erodibility factor (K value) at varying soil levels and slope classes (SOL_K{}.sol), management parameters that are subject to operation, and rotation (CNOP{}.mgt), and others watershed parameters (Eawag Aquatic Research, 2015).

For this project, five USGS gauge stations were used as measured data in the calibration and uncertainty analysis: station 12379500 – South Crow Creek near Ronan, station 12377150 – Mission Creek above the Reservoir, station 12381400 – South Fork Jocko River near Arlee, MT, station 12374250 – Mill Creek above Bassoo Creek, and station 12388700 – Flathead River at Perma.

Since we are dealing with HUC-12 units in SWAT and point source discharge at USGS gauge station, a scaling factor representing the proportion of the drainage area of the station to the entire HUC-12 unit. To rectify the scale mismatch, a scaling factor was applied to the raw USGS flow data to create a more accurate observation. The scaling factor was the ratio between the drainage area upstream of the USGS station and the total HUC-12 drainage area.

SUFI-2 is iterative; therefore, 1000 simulations were completed using the Latin hypercube sampling scheme to obtain a final calibrated set of optimized parameters (Eawag Aquatic Research, 2015).

3.4.3 SWAT-CUP Calibration Outputs for Flathead River at Perma, Montana USGS Station

The original HAWQS model was calibrated against USGS station 12388700 – Flathead River at Perma, MT to then use to produce simulations by editing SWAT input files using SWAT Editor.

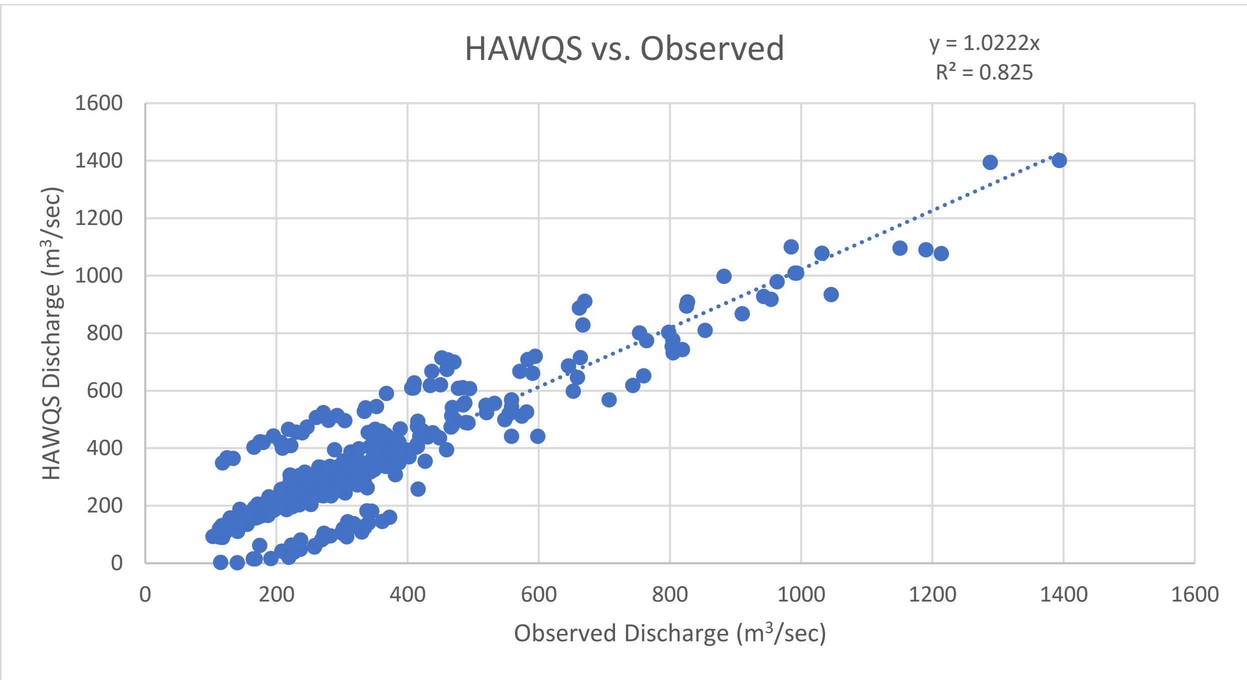

Figure 3.3 HAWQS Model Produced Discharge vs. Observed USGS Data, along with the Line of Best Fit and R^2 Value.

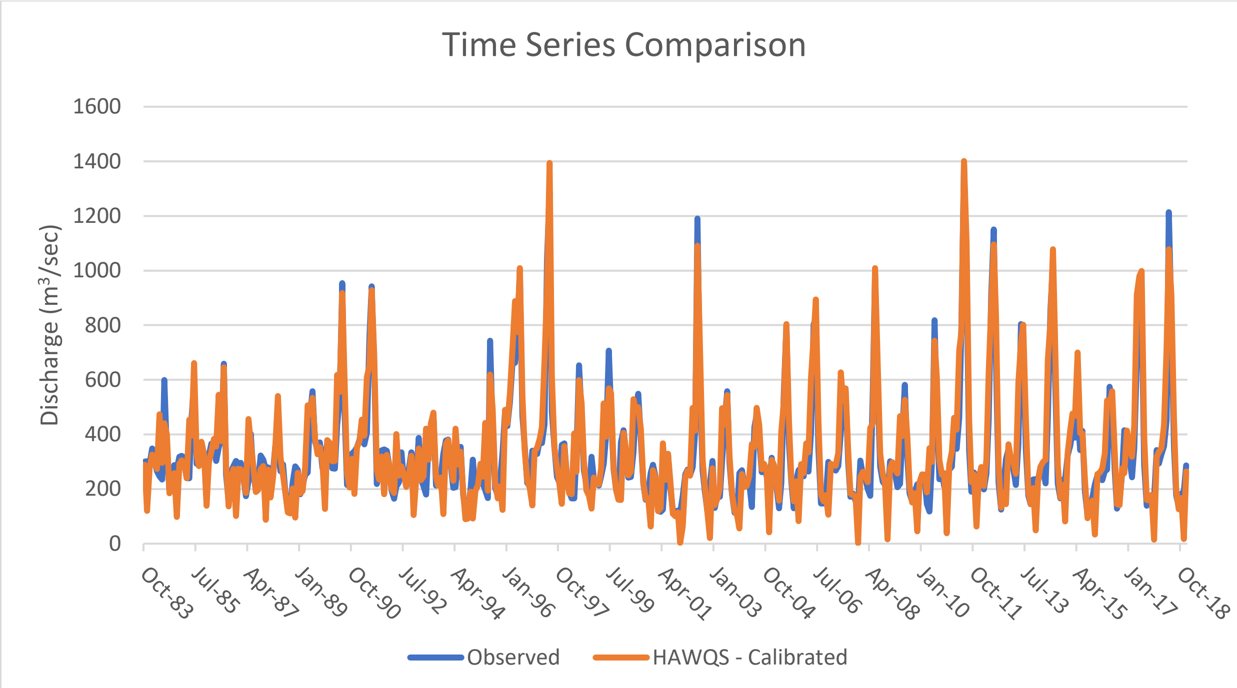

Figure 3.4 Comparison of HAWQS modeled discharge against observed USGS data.

3.5 SWAT Editor and Modeled Scenarios

SWAT Editor is a program that reads the project database generated at ArcSWAT, QSWAT, and HAWQS, allowing users to edit SWAT input files, execute SWAT simulations, perform sensitivity, auto-calibration, and uncertainty analysis. SWAT Editor is a standalone program and does not require GIS, which helps users share their projects with others that do not have GIS or much experience with GIS in general (U.S. Department of Agriculture ARS Grassland Soil and Water Research Laboratory & Texas A&M AgriLife Research, 2020).

SWAT Editor was useful for this project because the program allowed me to modify observed flow data input files to create dry, normal, and wet hydrologic condition scenarios, which were determined in the CSKT Water Rights Compact, Appendix 3.7 (more in Section 3.5.1) (CSKT Compact, 2015). Further, SWAT Editor permitted us to change the irrigation infrastructure efficiency and plant water stress management parameters simultaneous to the climatic scenarios.

3.5.1 Calculation of Dry, Wet, and Normal Years for Streamflow Discharge

Calculation and definition of dry, normal, and wet years were determined in the negotiation of CSKT – Montana Water Rights Compact and detailed in Appendix 3.7. The definition of dry, normal, and wet years is associated with river diversion allowances (RDAs), Minimum Enforceable Instream Flows (MEFs), and Target Instream Flows (TIFs) (e.g., there is a Dry Year MEF, and Normal or Wet Years have a TIF). The purpose of the RDAs, MEFs, and TIFs of the CSKT Water Rights Compact were established to better achieve fishery objectives, which also provides for existing irrigation uses (CSKT Compact, 2015).

An RDA signifies the volume of water identified in Appendix 3.2 and defined for wet, normal, and dry natural flow years that can be diverted or pumped to supply the FIIP water use right. RDAs are dedicated to serving irrigation headworks or pumping facilities for irrigated lands that are assessed and served by the FIIP. Further, RDAs that are used to serve irrigated lands are applicable over the April 15 through September 15 period and may be extended to no later than October 15 (CSKT Compact, 2015). RDAs are reported for “administered locations” and “incremental inflow locations.” Administered locations are irrigation headworks or pumping facilities where water measurement and seasonal accounting of the RDA volumes will occur. Incremental inflow locations are areas where small streams or other incidental sources contribute to the FIIP infrastructure; these are not intended for direct administration of RDA administered locations (CSKT Compact, 2015).

An instream flow right indicates streamflow retained in a watercourse to benefit the aquatic environment. Instream flow may include natural flow or stream flow affected by regular diversion or other modifications. In this case, natural flow is the rate and volume of water moving past a specified point on a natural stream, produced from a drainage area for which there have been no effects caused by diversion, storage, import, export, return flow, or changes in consumptive use (CSKT Compact, 2015). A water right for instream flow purposes is quantified for a stream reach and measured for enforcement purposes at a specific point (CSKT Compact, 2015). MEFs denote the schedule of monthly minimum enforceable streamflow levels that were agreed upon in the Compact and detailed in Appendix 3.1. Lastly, TIFs suggest the schedule of month instream flow levels defined for normal and wet years that are identified in Appendix 3.1 (CSKT Compact, 2015). Appendix 3.1 of the CSKT Water Rights Compact specifies the MEFs and TIFs of instream flow locations in the Jocko River Area, Mission Creek Area, and Little Bitterroot River Area, respectively. Appendix 3.2 specifies the water allocations for RDAs for RDA administrative areas.

The RDAs, MEFs, and TIFs were drawn from the Operational Improvements HYDROSS Model runs for the Jocko River and Mission Creek. The Little Bitterroot River draws on the 2009 Irrigated Lands Mapping HYDROSS Model. Each of the RDAs, MEFs, and TIFs were based on hydrologic conditions (i.e., dry, normal, wet years) as determined from modeled natural flow near the mouth of the Jocko River, Mission Creek, Crow Creek, and on the Little Bitterroot River. Note: streamflow at these locations is impacted by storage regulations, diversions, and return flows and natural flow, therefore, it cannot be directly measured at these locations (CSKT Compact, 2015). Indicator gages were used as surrogates to the measurement of natural flow at the mouth of the Jocko River, Mission Creek, Crow Creek, and the Little Bitterroot River. The surrogates are then used to determine the hydrologic condition (CSKT Compact, 2015).

The determination of dry, normal, and wet years for the purpose of defining RDAs, MEFs, and TIFs was based on modeled natural streamflow for the April through July forecasting period of the 1983 – 2002 study period. Dry years are the four years for which the April – July natural flow is below the 80th-percentile exceedance level. Wet years are the four years with April – July natural flow is above the 20th-percentile exceedance level. Normal years are those falling between the 80th- and 20th-percentile exceedance levels (CSKT Compact, 2015).

For the purposes of this project, RDAS, TIFs, and MEFs are critical in exploring vulnerable areas of the FIIP system that fall below delivering target volumes of irrigation water, as well as investigating how the enforcement of CSKT senior water rights will potentially impact agricultural pursuits in the Lower Flathead River watershed.

3.5.2 Editing Input Files Using SWAT Editor

To begin, a user must successfully link to databases associated with the SWAT model. This includes connecting to the SWAT Project Geodatabase, SWAT Parameter Geodatabases, SWAT Soils Database, and the SWAT Executable Folder. Once connected, I began to edit the input streamflow data to reflect the varying hydrologic conditions (i.e., dry, normal, wet year). This requires selecting the Point Source Discharge in the Edit SWAT Input tab, then selectin the subbasin of interest. The program then prompts users to modify the input streamflow data by inputting a modified text file reflecting altered hydrologic conditions (U.S. Department of Agriculture ARS Grassland Soil and Water Research Laboratory & Texas A&M AgriLife Research, 2020). For this project, I modified 9 subbasins, because these basins had hay and/or alfalfa grown within the boundaries. Once the text files are changed, I rewrote the SWAT Input Files, also under the Edit SWAT Input tab. Once the files are rewritten, I changed the management files for each subbasin to modify the infrastructure efficiency and crop water stress, which highlights how often a field is being watered. Both the infrastructure efficiency (IRR_EFF) and water stress (WSTRS) percent values fall between 0 and 1, where an IRR_EFF value of 1 is a completely efficient irrigation system and a WSTRS value of 0.9 means the crops are being watered every week. A WSTRS value of less than 0.9 means the crops are being watered less frequently (R. Srinivasan, personal communication, April 10, 2020). The term "WSTRS" is an abbreviated version of "AUTO_WSTRS", which signifies the water stress threshold that triggers irrigation, and is a variable that can be changed for auto-irrigation initialization. In SWAT, auto-initialization is useful as an alternative to specifying fixed amounts and time for irrigation; instead, the user can allow the model to apply water as need by plant (i.e., alfalfa or hay) (USDA ARS Grassland Soil and Water Research Laboratory & Texas A&M AgriLife Research, 2018). In this case, it is also useful as a proxy for the instantaneous measurements of discharge throughout the FIIP canals and pump stations. Once the values were written, the management input files were rewritten for a new SWAT simulation run. Once the two input files were successfully edited and rewritten, SWAT Editor can run an updated simulation with new streamflow and management input data. After running the simulation, the output files pertaining to the reach and subbasins were imported to the project output database for analysis.

CHAPTER 4. Results

In this chapter, I highlight the simulated results of the SWAT model. To address my research questions, I adjusted several different model inputs to simulate potential hydrologic and legal or management scenarios that could occur given the current status of the CSKT water rights Compact and pending Settlement Agreement.

4.1 Influence of FIIP infrastructure on Basin Hydrology

An initial hypothesis influencing this research is that irrigation on the FIIP (and irrigation efficiency), (i.e., the state of project infrastructure), is a driving factor in basin streamflow. As the infrastructure of the FIIP is wholly contained in the Lower Flathead watershed (see Figure 4.7), it was appropriate to initially look for any changes to streamflow as a result of simulated changes in efficiency at the outlet for subbasin 38 – Flathead River at Perma, MT – also the outlet for the entire Lower Flathead basin, as the Flathead empties in the Clark Fork River. To investigate the potential influence of FIIP irrigation infrastructure on basin hydrology, I simulated varying degrees of plant water stress, or watering frequency (e.g., 0.7 and 0.9 WSTRS), and irrigation system efficiency (e.g., 0.0, 0.5, and 1.0 efficiency) under the three hydrologic scenarios set forth in the CSKT compact (Figures 4.1). The WSTRS parametric value serves as a proxy that signifies different amounts of water diverted from streamflow to alfalfa field; a 0.9 WSTRS value indicates a field be water more often, thus diverting more streamflow. A 0.7 WSTRS value designates a field be water less often, which would need less water. For simulated efficiencies, 0.0 efficiency signifies when all of the water volume diverted in the system is lost to infiltration (100% inefficient); 0.5 efficiency suggests when half of the water volume diverted in the system is loss from infiltration; 1.0 efficiency indicates a system where no water is loss in the transport of water for irrigation.

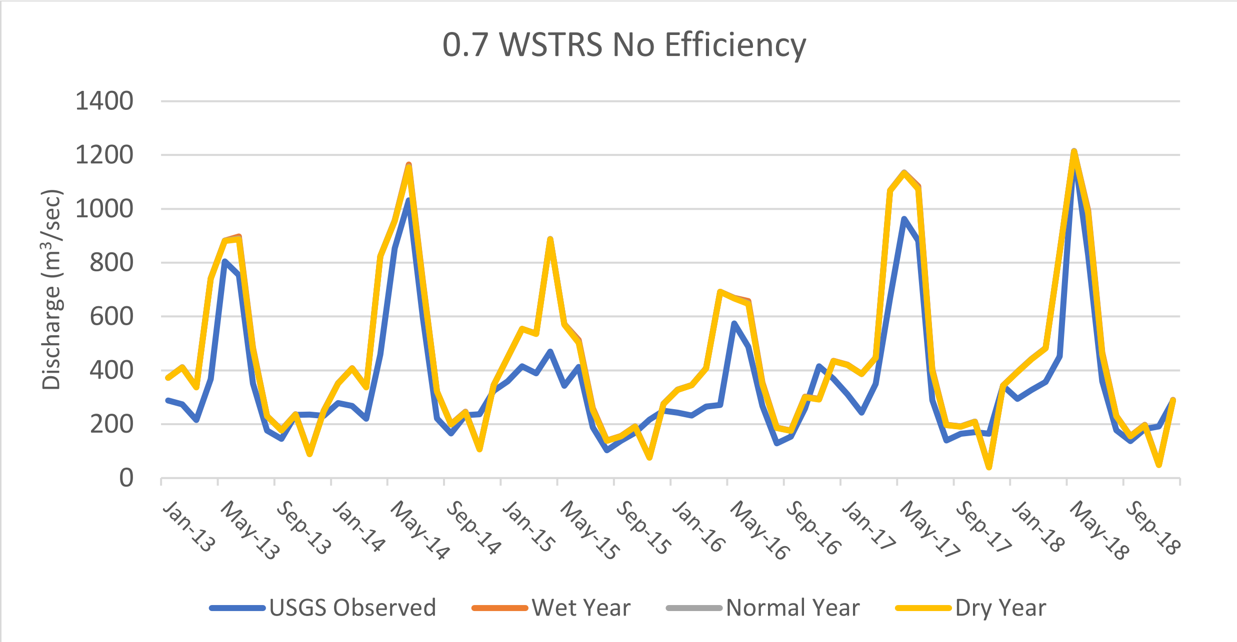

Figure 4.1 Flathead River at Perma, MT simulated discharge in a system watered once every three weeks (WSTRS = 0.7), and an irrigation system operating under no efficiency (0.0). The pattern is displayed from 2013-2018 for ease of visual inspection; see appendix for full modeled data from 1983-2018. This modeled hydrograph is produced at the output of HUC 12 number 170102120607.

Figure 4.1 denotes the minute impact irrigation system efficiency and watering frequency has on the discharge of water at the outlet of the entire simulated subbasin. (see the red triangle of Figure 4.2). Figure 4.1 hydrograph suggests that irrigation system efficiency and watering frequency do not significantly impact the regional hydrology of our simulated watershed (e.g., Lower Flathead River watershed). There is little impact on the regional hydrology, in the order of +/- 1 m^3/sec. I also constructed an additional five complementary simulated hydrographs with varying degrees of irrigation system efficiency and water stress, like that depicted in Figure 4.1 above. Each hydrograph is near identical to Figure 4.1 in that there is little to no variability in discharge attributed to system efficiency and water stress (WSTRS) according to the model.

An important note for interpreting these results, in HAWQS simulations, is that some water used for irrigation originates from a pumping station located upstream of the SKQ Dam, in addition to rainfall, snowfall, and mountain runoff.

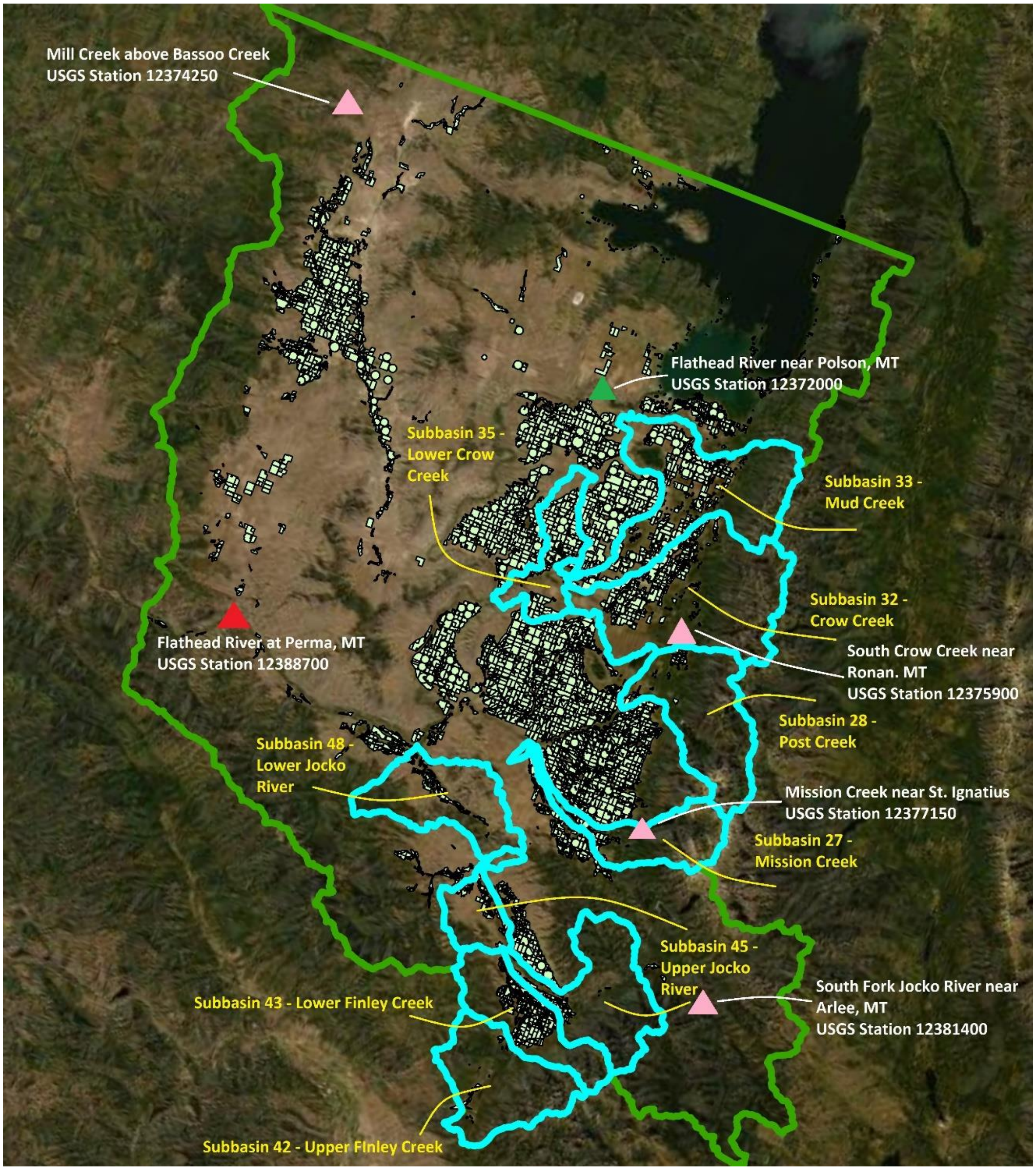

Figure 4.2 Locations of subbasins (turquoise boundary) on the Flathead Reservation with FIIP instream flow rights and growing alfalfa or hay. The yellow polygons indicate FIIP historically irrigated acreage on the Reservation (green boundary). Also present are six USGS stations located on the Flathead Reservation (triangle). Note that five of the six stations were used for calibration and validation of the HAWQS model, excluding station 12372000 – Flathead River at Polson. Flathead River is the input location of the HAWQS model (green triangle), and the terminus located at station 12388700 – Flathead River at Perma, MT (red triangle).

With this knowledge, I decided to divert my focus towards investigating how CSKT Compact-derived hydrologic condition (e.g., dry, normal, and wet years) (see section 4.4. for simulated hydrographs and section 3.5.1 of Chapter 3 for the calculation of a dry, normal, and wet year), water stress (i.e., water stress – WSTRS) (see section 4.3), and irrigation system efficiency (also see section 4.3) impact the hydrology of individual subbasins that possess both FIIP instream flow rights and grow alfalfa larger than 1 km^2 in area. The rationale for this analysis was to assess subbasins with enforceable CSKT instream flow rights as a result of the Compact that are also influenced or could be influenced by changes in irrigation infrastructure and practices (i.e. FIIP improvements).

4.2 FIIP Hydrology for Simulated Subbasins without Efficiency Improvements to the FIIP

The nine subbasins included in Table 4.1 possess enforceable FIIP instream flow rights and grow alfalfa or hay. Table 4.1 also depicts the total number of months in the simulated period (1983-2018) in which any of the nine subbasins fall under Compact-derived MEF and TIF streamflow discharge thresholds. Further, the table highlights the percentage of total months the subbasins fall under each threshold value. As for the irrigation season values, the timeframe used was also the simulated period from October 1983 to December 2018, however, it only accounted for irrigation season months (i.e., April through September in western Montana). Also included in Table 4.1 is the area of the subbasin growing alfalfa or hay (km^2), the total area of the subbasin (km^2), and the proportion of the subbasin growing alfalfa or hay (%).

Table 4.3 Comparison of the number of months falling under MEF and TIF thresholds for each subbasin containing both FIIP irrigation and CSKT instream flow rights (total months for year-round simulation: n = 423; irrigation season simulation: n = 210).*

	With Irrigation				**Without Irrigation**						
	Year-Round		**Irrigation Season (Apr. - Sept.)**		**Year-Round**		**Irrigation Season (Apr. - Sept.)**		**Area of Subbasin Growing Alfalfa/Hay**	**Total Area of Subbasin**	**Proportion of Subbasin Growing Alfalfa/Hay**
Subbasin 27 Mission Creek	**%**	**n=**	**%**	**n=**	**%**	**n=**	**%**	**n=**	**km^2**	**km^2**	**%**
Dry Year % of Total Months Under MEF Threshold	20.6	87	0.5	1	22.0	93	0	0	6.6	218.3	3.0
Normal Year % of Total Months Under TIF Threshold	20.6	87	0.5	1	22.2	94	0	0			
Wet Year % of Total Months Under TIF Threshold	20.6	87	0.5	1	22.2	94	0	0			
Subbasin 28 Post Creek											
Dry Year % of Total Months Under MEF Threshold	5.2	22	0	0	30.7	130	50.5	106	5.4	118.4	4.6
Normal Year % of Total Months Under TIF Threshold	5.2	22	0	0	35.0	148	57.1	120			
Wet Year % of Total Months Under TIF Threshold	5.2	22	0	0	33.6	142	56.2	118			
Subbasin 32 Crow Creek											
Dry Year % of Total Months Under MEF Threshold	34.3	145	17.1	36	18.9	80	2.9	6	36.2	193.9	18.7
Normal Year % of Total Months Under TIF Threshold	34.8	147	18.1	38	18.7	79	2.9	6			
Wet Year % of Total Months Under TIF Threshold	35.5	150	19.0	40	18.4	78	2.9	6			
Subbasin 33 Mud Creek											

Dry Year % of Total Months Under MEF Threshold	61.7	261	37.1	78	46.3	196	22.9	48	48.8	169.3	28.8
Subbasin 35 Lower Crow Creek											
Dry Year % of Total Months Under MEF Threshold	4.5	19	9.0	19	0	0	0	0			
Normal Year % of Total Months Under TIF Threshold	2.4	10	4.8	10	0	0	0	0	32.4	478.4	6.8
Wet Year % of Total Months Under TIF Threshold	1.9	8	3.8	8	0	0	0	0			
Subbasin 42 Upper Finley Creek											
Dry Year % of Total Months Under MEF Threshold	12.3	52	0	0	11.3	48	0	0	1.3	105.6	1.3
Subbasin 43 Lower Finley Creek											
Dry Year % of Total Months Under MEF Threshold	13.7	58	6.2	13	8.3	35	0	0			
Normal Year % of Total Months Under TIF Threshold	12.8	54	4.8	10	8.3	35	0	0	19.0	190	10.0
Wet Year % of Total Months Under TIF Threshold	14.2	60	5.7	12	8.3	35	0	0			
Subbasin 45 Upper Jocko River											
Dry Year % of Total Months Under MEF Threshold	0	0	0	0	0	0	0	0			
Normal Year % of Total Months Under TIF Threshold	0	0	0	0	0	0	0	0	13.2	720	1.8
Wet Year % of Total Months Under TIF Threshold	0	0	0	0	0	0	0	0			
Subbasin 48 Lower Jocko River											
Dry Year % of Total Months Under MEF Threshold	0	0	0	0	0	0	0	0	3.0	1675	0.2
Normal Year % of Total Months Under TIF Threshold	0	0	0	0	0	0	0	0			

Wet Year % of Total Months Under TIF Threshold	0	0	0	0	0	0	0	0			

**Note: the timeframe for year-round simulations is from October 1983 to December 2018, hence the odd number of months. The timeframe for irrigation season simulations is from April to September for each year from 1983 to 2018*

Table 4.1 includes values for year-round and irrigation season timeframes. The year-round scenario accounts for all months of the year, including those that fall outside of the irrigation season in Montana (i.e., all twelve calendar months). I included the column to be able to compare the differences in vulnerability (i.e., number of months the subbasin falls under a MEF or TIF threshold) with and without the hydrologic influence of irrigation.

At first glance, Table 4.1 shows that the Upper and Lower Jocko River subbasins (45 and 48) have no risk in falling under the MEF and TIF values in the subbasin reach. Also, something to note is that both subbasins have less than 2% of the total subbasin area designated for the cultivation of alfalfa, so it can be assumed that irrigation in this subbasin is not a driving factor in influencing streamflow.

In all subbasins, except for subbasin 35 Lower Crow Creek, the percentage of time each subbasin falls under a MEF or TIF is less during the irrigation season when compared to year-round data, which is surprising given that I would generally assume more water is pulled from the streams during irrigation season, thus potentially contributing to streamflow falling below MEF and TIF threshold values. Further, in all subbasins except for Post Creek (subbasin 28), the percentage of time each subbasin falls under a MEF or TIF threshold either remains zero or decreases when transitioning from irrigation to no irrigation in modeled scenarios.

In Mission Creek (subbasin 27), the percentage of months in which modeled stream discharge falls under MEFs and TIFs is higher in a system that has no irrigation occurring than a system with irrigation. Conversely, when analyzing irrigation season months only, the percentage of months that discharge falls under MEFs and TIFs is greater in a system with irrigation than a system without irrigation, which is generally a more intuitive finding given that

I assume more water is left in stream without active irrigation (although timing considerations will impact streamflow in relation to MEFs and TIFs).

In Post Creek (subbasin 28), the percentage of months in which modeled discharge falls under MEFs and TIFs is greater in a system that has no irrigation occurring than a system with irrigation. However, I found that during irrigation season conditions, the percentage of months in which modeled discharge falls under MEFs and TIFs is higher in a system without irrigation than a system with irrigation. Crow Creek (subbasin 32) presented a counter and more predictable finding, in that the percentage of months in which modeled discharge falls under MEFs and TIFs is higher in a system that has irrigation occurring than a system without irrigation.

Mud Creek (subbasin 33) seems to be the most vulnerable of all the subbasins analyzed, with the highest percentage of months in which modeled stream discharge falls below MEF and TIF thresholds. Specifically, the percentage of months in which modeled discharge falls under MEFs and TIFs in Mud Creek is higher in a system that has irrigation occurring than a system without irrigation. It is also important to note this subbasin has the highest proportion of the subbasin devoted towards growing alfalfa (28.8%). Lower Crow Creek and Upper and Lower Finley Creek (subbasins 35, 42 and 43, respectfully) all follow suit and show that the percentage of months in which modeled discharge falls under MEFs and TIFs is higher in a system that has irrigation occurring than in a system without irrigation.

4.3 Role of FIIP Infrastructure Efficiency and Water Stress in Meeting MEFs and TIFs without Improvement to FIIP Infrastructure

As a further investigation of the relationship between irrigation, streamflow, and legally-enforceable instream flows, below I highlight how the irrigation efficiency of the simulated FIIP system could affect stream discharge from subbasins that contain the smallest (0.2% total area; Lower Jocko River, subbasin 48) and largest (28.8%; Mud Creek, subbasin 33) proportion of the subbasin growing alfalfa and hay—the most common and high-intensity irrigated crop on the project. I also analyzed the same modeled scenario in Post Creek (subbasin 28), because the proportion of the subbasin growing alfalfa is between the two extremes at 4.8% of the total subbasin area in hay/alfalfa agriculture.

All the subbasin hydrographs visualized in this section further align with results reported in section 4.1 in that the degree of watering frequency (i.e., 0.7 and 0.9 WSTRS) on irrigated lands and irrigation system efficiency (i.e., 0.5, 1.0 Eff) do not produce a significant impact on the local hydrologic output of each subbasin—at least as modeled given the assumptions of the SWAT model (see Figures 4.3-4.8).

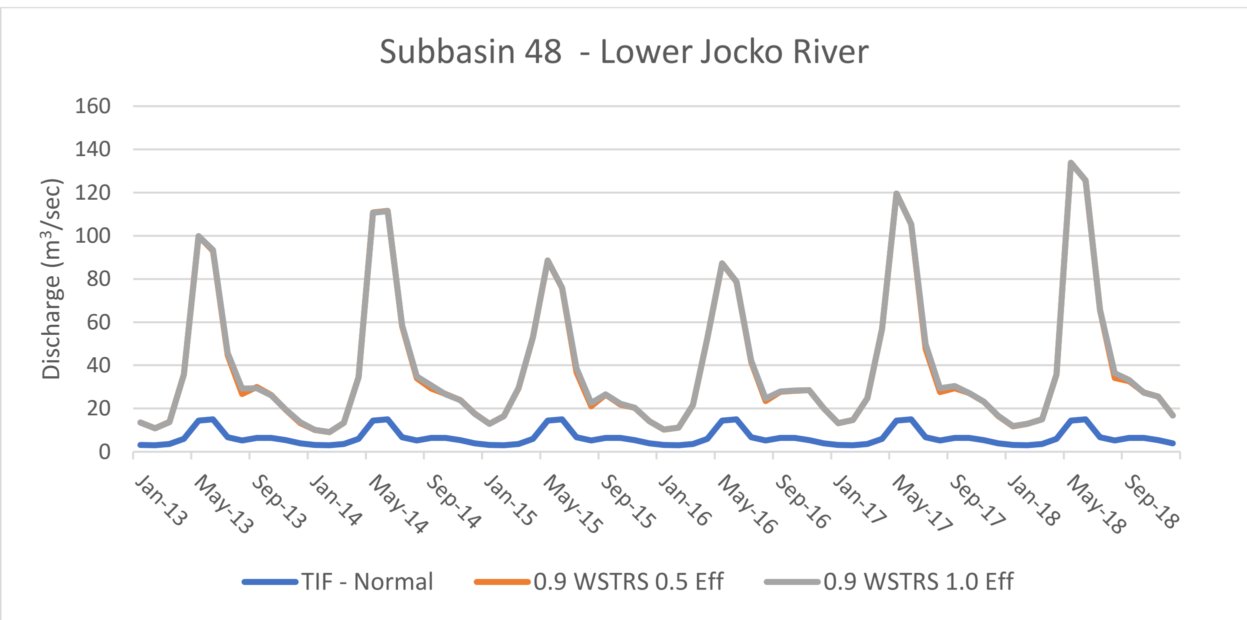

Figure 4.3 Lower Jocko River simulated discharge in a system watered every week (WSTRS = 0.9), operating under a half (0.5) and fully efficient (1.0) irrigation system.

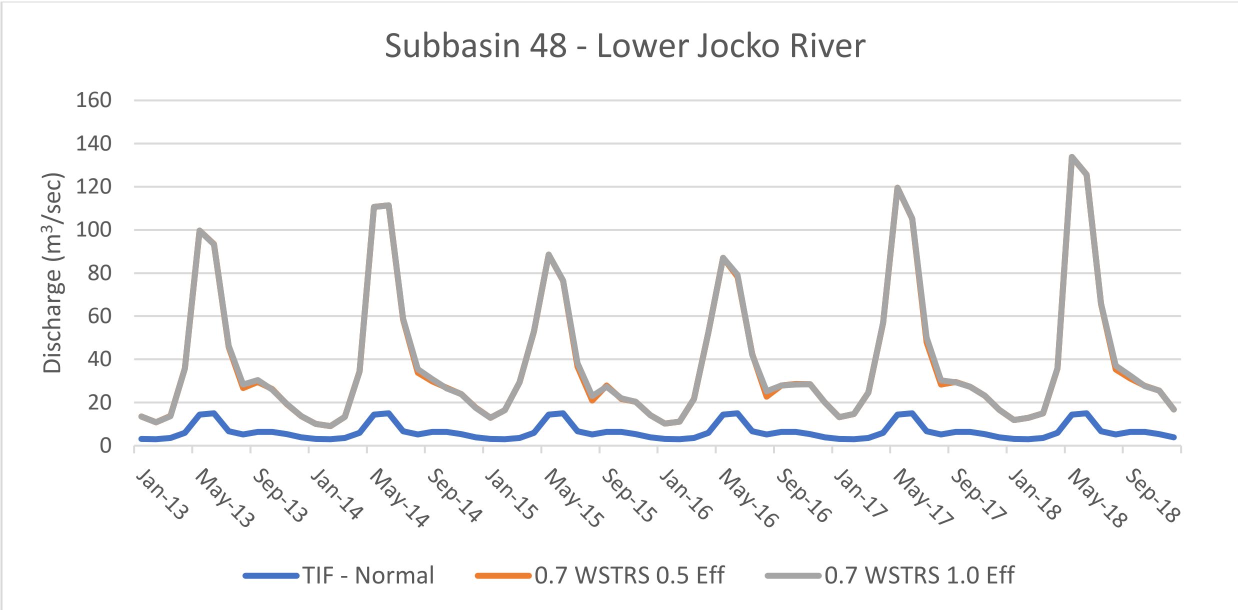

Figure 4.4 Lower Jocko River simulated discharge in a system watered once every three weeks (WSTRS = 0.7), operating under a half (0.5) and fully efficient (1.0) irrigation system.

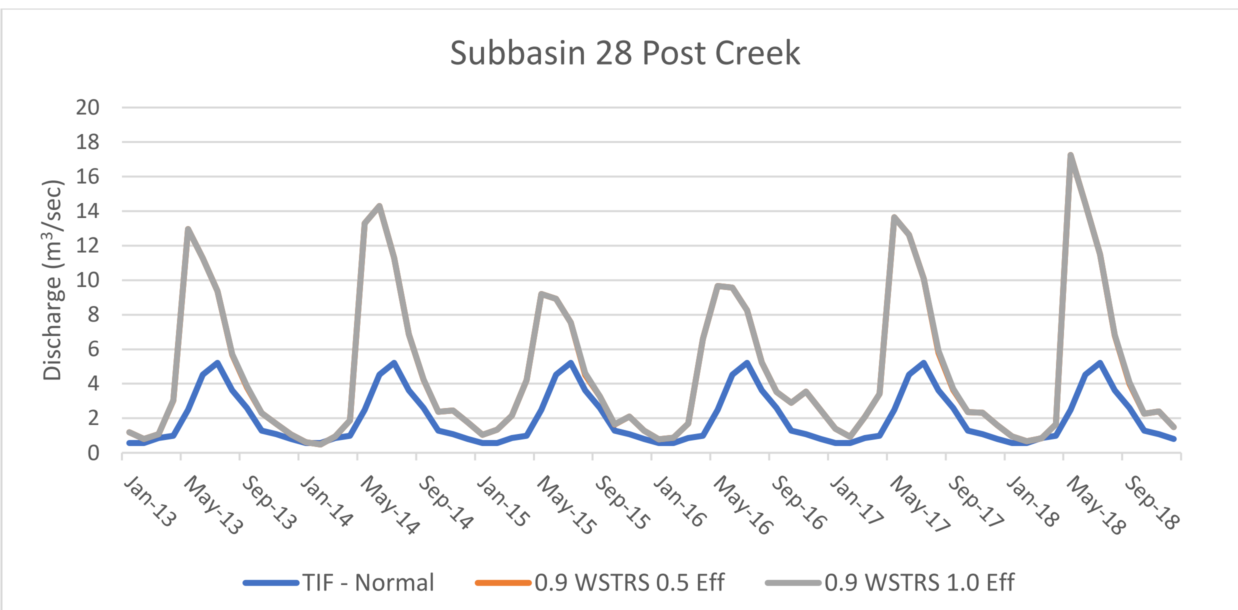

Figure 4.5 Post Creek simulated discharge in a system watered every week (WSTRS = 0.9), operating under a half (0.5) and fully efficient (1.0) irrigation system.

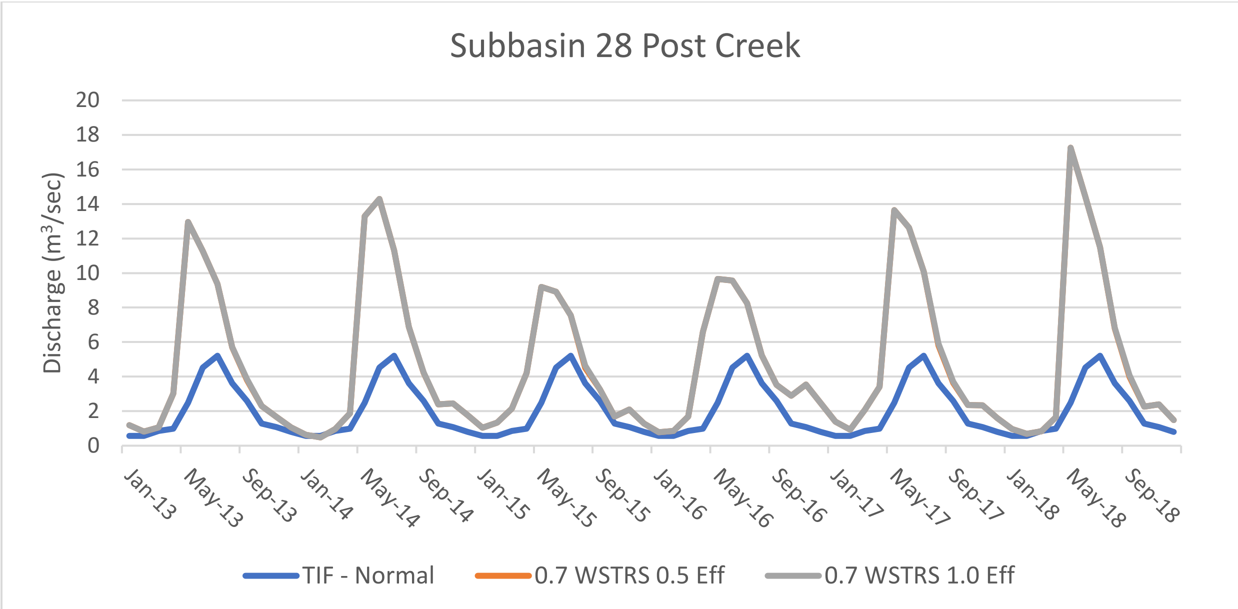

Figure 4.6 Post Creek simulated discharge in a system watered once every three weeks (WSTRS = 0.7), operating under a half (0.5) and fully efficient (1.0) irrigation system.

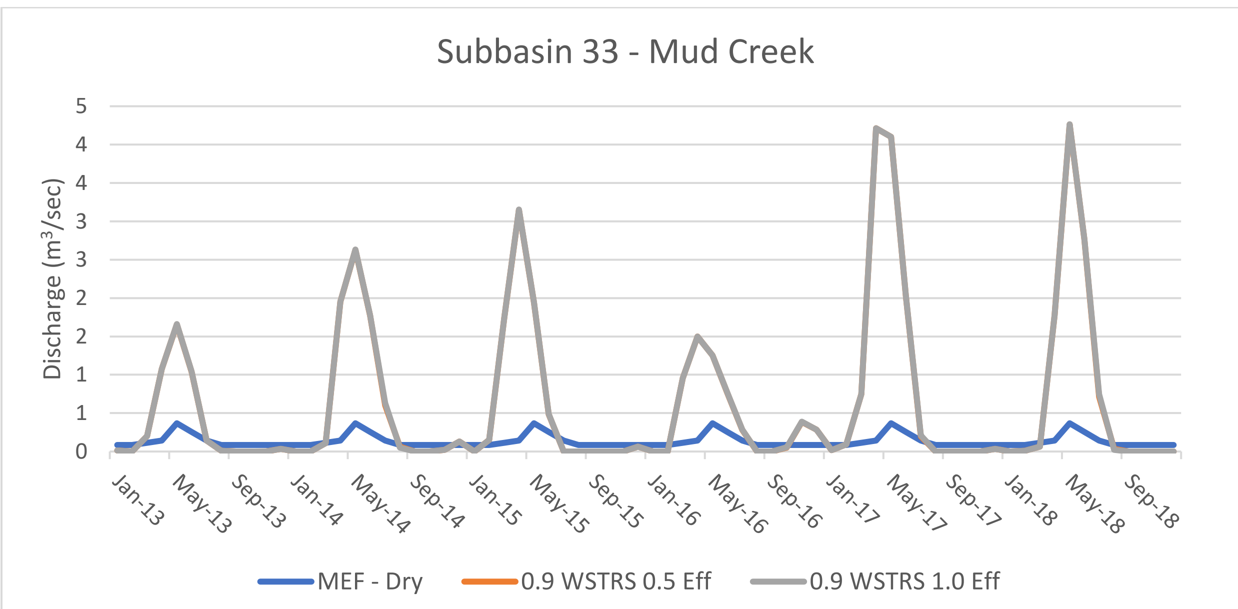

Figure 4.7 Mud Creek simulated discharge in a system watered every week (WSTRS = 0.9), operating under a half (0.5) and fully efficient (1.0) irrigation system.

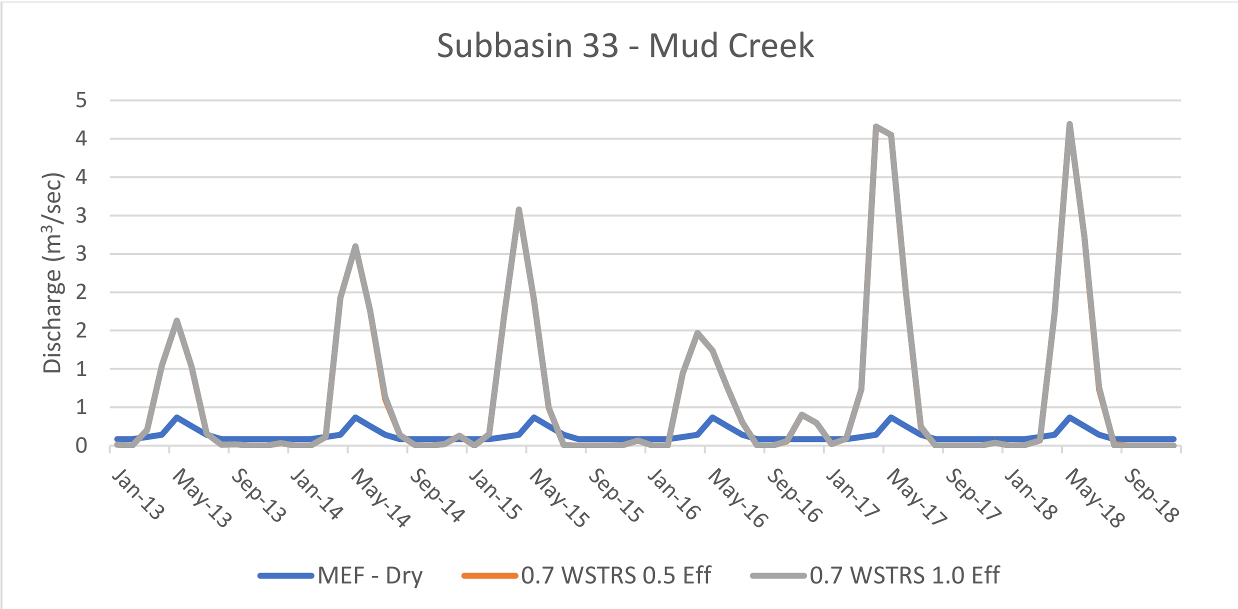

Figure 4.8 Post Creek simulated discharge in a system watered once every three weeks (WSTRS = 0.7), operating under a half (0.5) and fully efficient (1.0) irrigation system.

4.4 Role of Compact-Derived Hydrologic Conditions in Meeting MEFs and TIFs modeled with and without Irrigation Deliveries

In this section I explore how the dry, normal, or wet year determinations (thresholds) in the CSKT compact could influence the ability of a subbasin to stay above a MEF or TIF threshold. Reported values were calculated using all months of the simulation. Table 4.2 exhibits the least, moderate, and most vulnerable subbasins relative to the nine subbasins used for this analysis.

Table 4.2 Subbasins at varying levels of vulnerability to falling below MEF or TIF thresholds in a system with and without irrigation.

Dry Year				
		Least Vulnerable	Vulnerable	Most Vulnerable
		Subbasin 48 - Lower Jocko River	Subbasin 32 - Crow Creek	Subbasin 33 - Mud Creek
With Irrigation	Number of Months Under MEF Threshold	0	145	261
	Percentage of Total Months Under MEF Threshold (%)	0	34.3	61.7
Without Irrigation	Number of Months Under MEF Threshold	0	80	196
	Percentage of Total Months Under MEF Threshold (%)	0	18.9	46.3
Normal Year				
		Subbasin 48 - Lower Jocko River	Subbasin 43 - Lower Finley Creek	Subbasin 32 - Crow Creek
With Irrigation	Number of Months Under TIF Threshold	0	54	147
	Percentage of Total Months Under TIF Threshold (%)	0	12.8	34.8
Without Irrigation	Number of Months Under TIF Threshold	0	35	79
	Percentage of Total Months Under TIF Threshold (%)	0	8.3	18.7
Wet Year				
		Subbasin 48 - Lower Jocko River	Subbasin 27 - Mission Creek	Subbasin 32 - Crow Creek
With Irrigation	Number of Months Under TIF Threshold	0	87	150

	Percentage of Total Months Under TIF Threshold (%)	0	20.6	35.5
Without Irrigation	Number of Months Under TIF Threshold	0	94	78
	Percentage of Total Months Under TIF Threshold (%)	0	22.2	18.4

In Table 4.2, the modeled results show that the Lower Jocko River is resilient to varying future hydrologic conditions (i.e., dry, wet, and normal years) relative to MEFs and TIFs determined in the Compact. Also, it may be important to note that the Upper Jocko River shares the same resilient nature as the Lower Jocko River, potentially emphasizing the climate resilient nature of the Jocko drainage in meeting Compact goals, specifically relative to changes in irrigation or irrigation infrastructure.

For a dry year simulation, the Lower Jocko River is at virtually no risk of falling under the TIF threshold value (see Figure 4.9). I considered Crow Creek vulnerable because the proportion of time the subbasin falls under the designated MEF threshold in a dry year with and without irrigation is 34.3 % and 18.9%, respectively (see Figure 4.10). I considered Mud Creek the most vulnerable of all modeled subbasins during a dry year; the percentage of time stream discharges falls under the MEF value in a system with and without irrigation is 61.7% and 46.3% respectfully (see Figure 4.11).

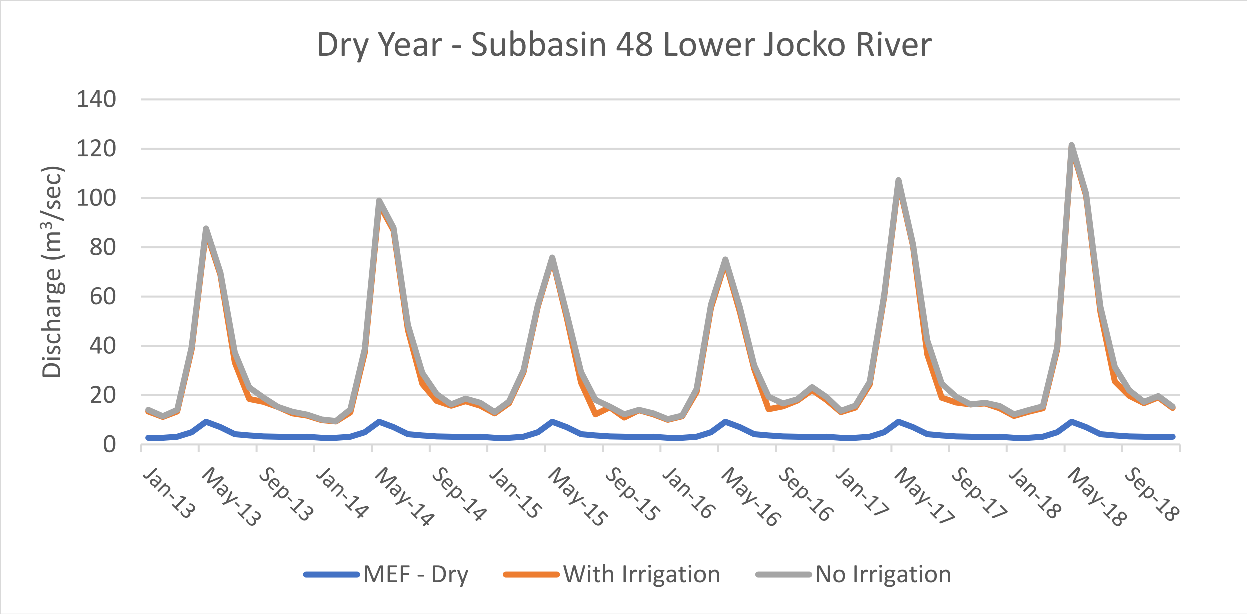

Figure 4.9 Dry year simulated hydrograph for the Lower Jocko River, comparing the output discharge of a system with (orange) and without (grey) irrigation occurring and modeled against Compact-derived MEF threshold values (blue).

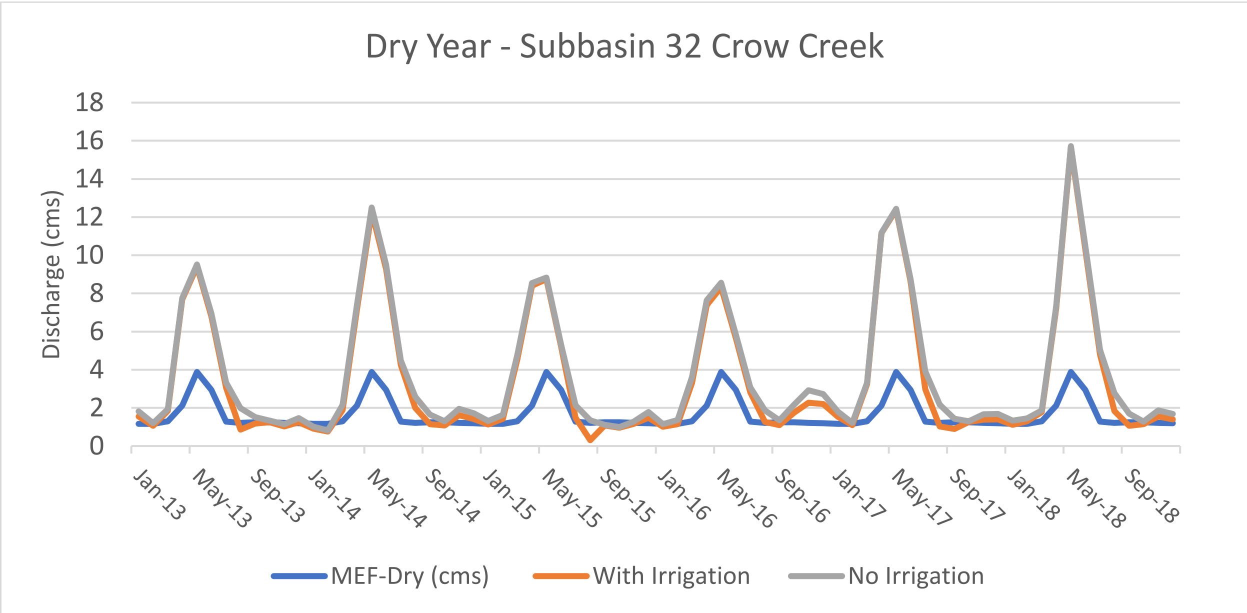

Figure 4.10 Dry year simulated hydrograph for Crow Creek, comparing the output discharge of a system with (orange) and without (grey) irrigation occurring and modeled against Compact-derived MEF threshold values (blue).

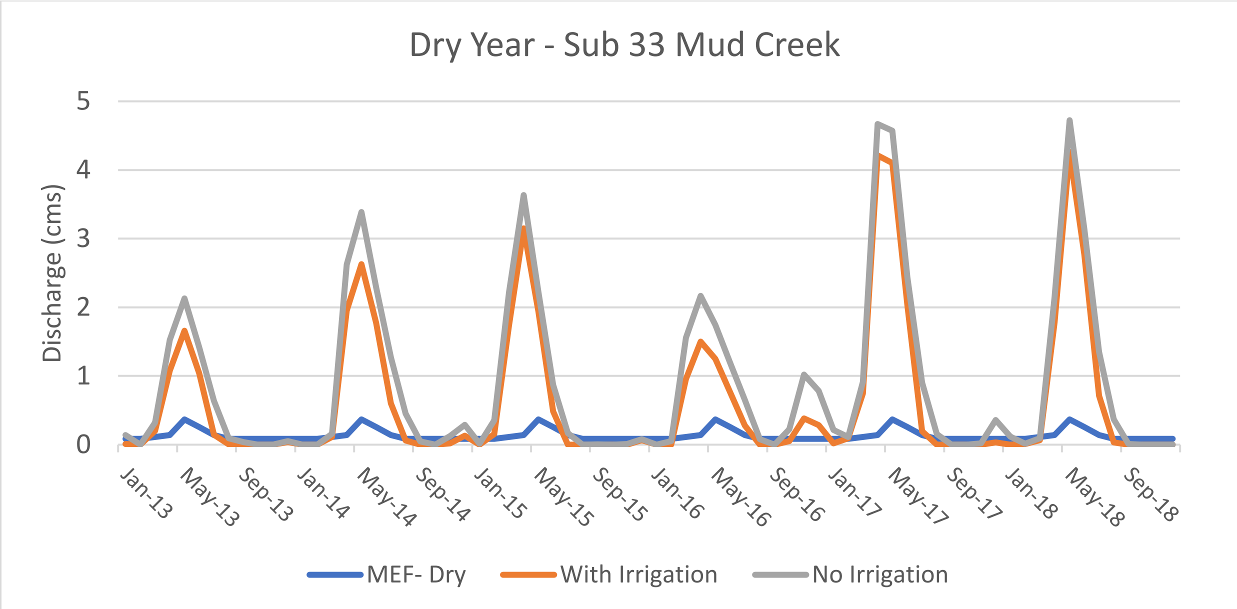

Figure 4.11 Dry year simulated hydrograph for Mud Creek, comparing the output discharge of a system with (orange) and without (grey) irrigation occurring and modeled against Compact-derived MEF threshold values (blue).

For normal year simulations, the Lower Jocko River is at virtually no risk of falling under the TIF threshold value (see Figure 4.12). I considered Lower Finley Creek vulnerable because the proportion of time the modeled subbasin stream discharge falls under the designated TIF threshold in a system with and without irrigation is 12.8% and 8.3%, respectively (see Figure 4.13). Further, I considered Crow Creek the most vulnerable of all subbasins during a normal year, because the percentage of time the output discharge falls under the TIF value in a system with and without irrigation is 34.8% and 18.7% (see Figure 4.14).

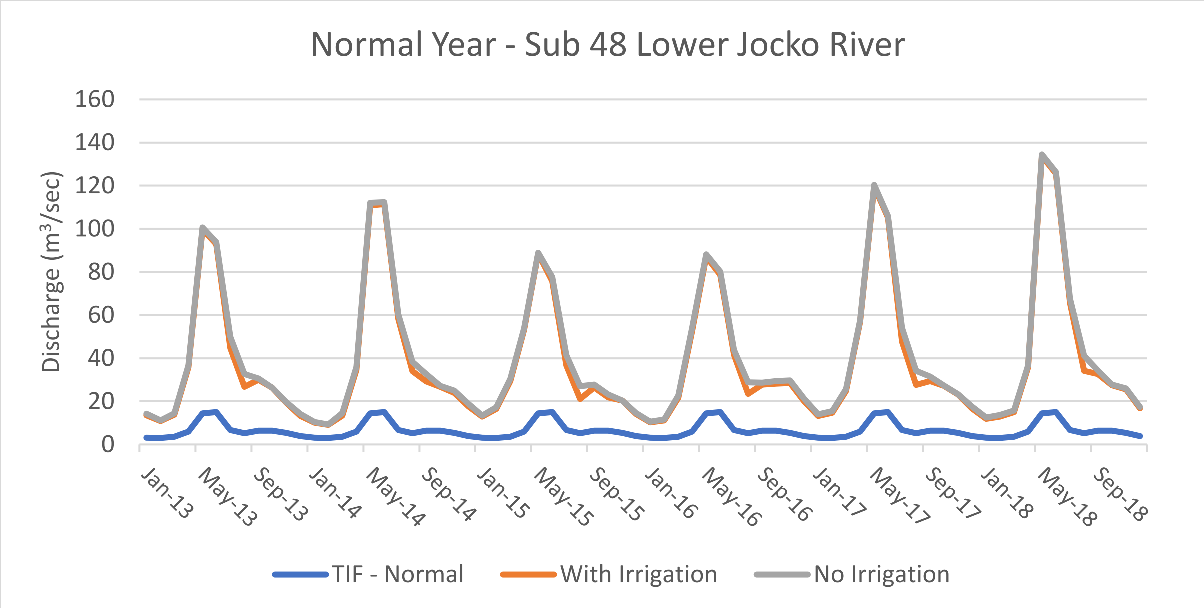

Figure 4.12 Normal year simulated hydrograph for the Lower Jocko River, comparing the output discharge of a system with (orange) and without (grey) irrigation occurring, and modeled against Compact-derived TIF threshold values (blue).

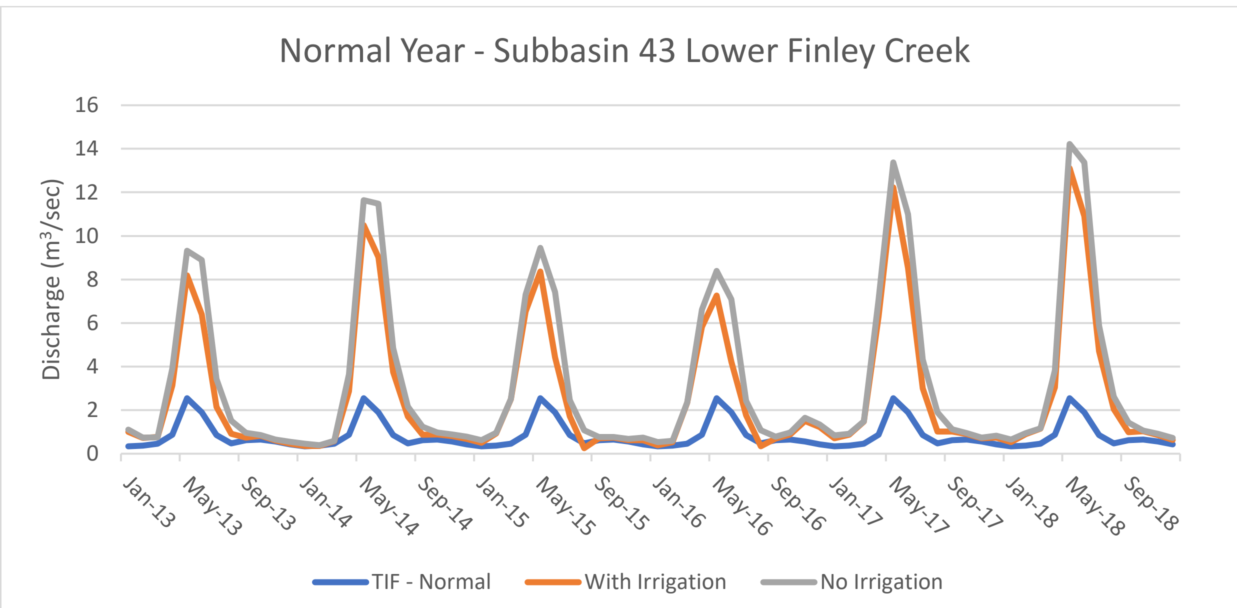

Figure 4.13 Normal year simulated hydrograph for Lower Finley Creek, comparing the output discharge of a system with (orange) and without (grey) irrigation occurring, and modeled against Compact-derived TIF threshold values (blue).

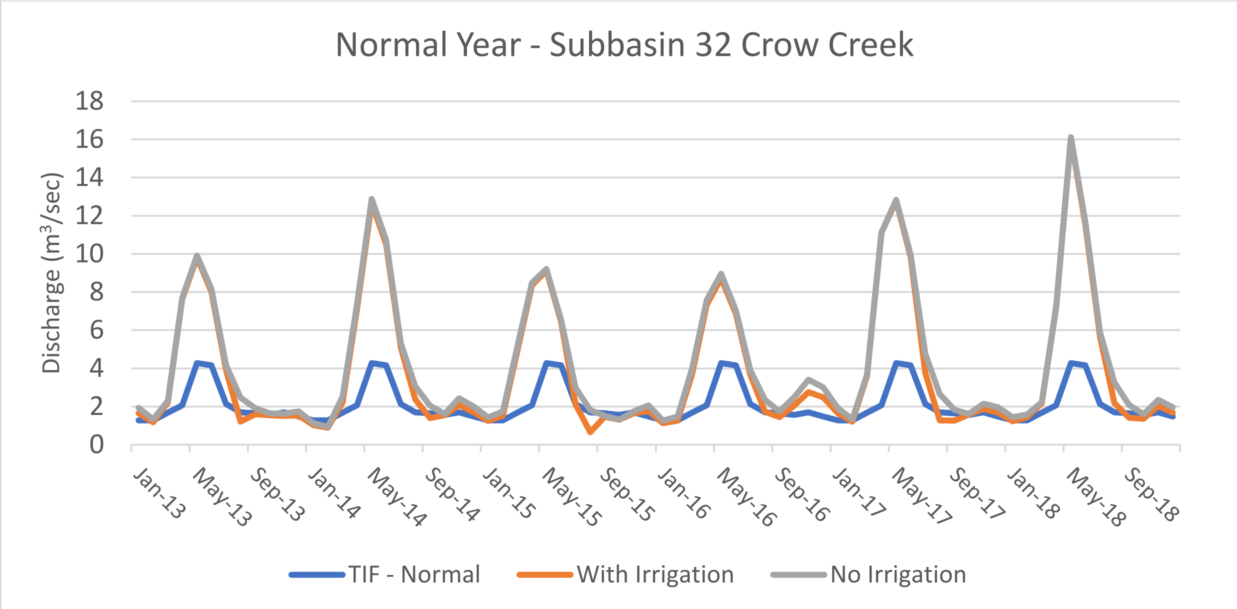

Figure 4.14 Normal year simulated hydrograph for Crow Creek, comparing the output discharge of a system with (orange) and without (grey) irrigation occurring, and modeled against Compact-derived TIF threshold values (blue).

In wet year simulations, the Lower Jocko River demonstrates virtually no risk of falling under the TIF threshold value (see Figure 4.15). I considered vulnerable Mission Creek in a normal water year because the proportion of time the subbasin falls under the designated TIF threshold in a system with and without irrigation is 20.6 % and 22.2%, respectively (see Figure 4.16). I considered Crow Creek the most vulnerable of all subbasins in a wet year simulation, because the percentage of time the output discharge falls under the TIF value in a system with and without irrigation is 35.5% and 18.4% (see Figure 4.17).

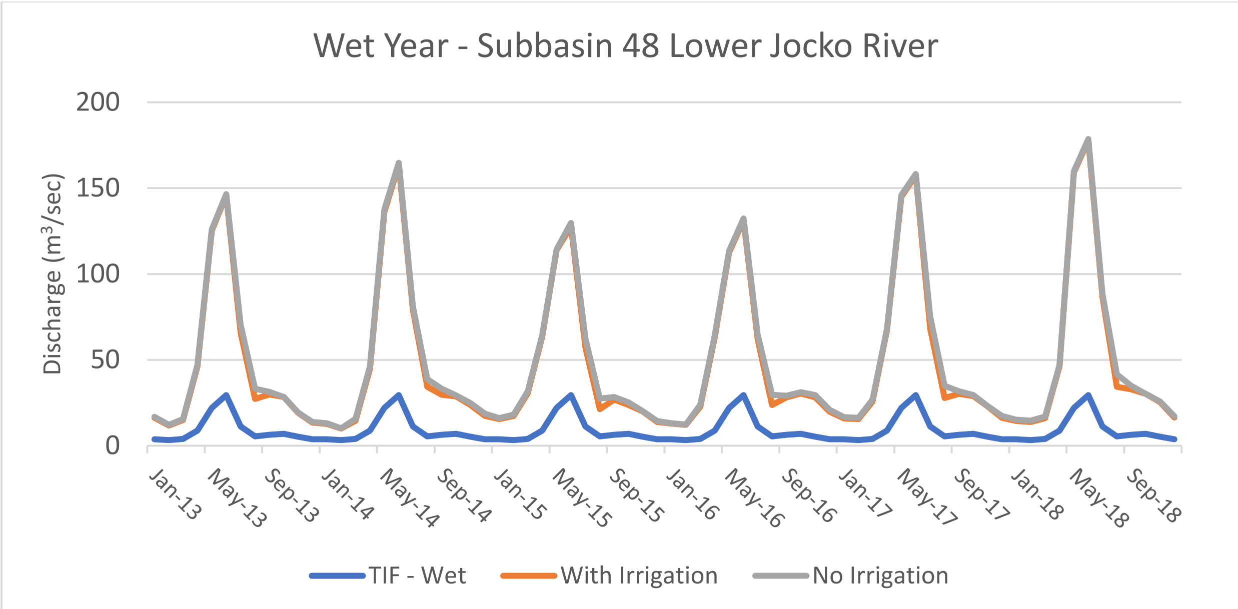

Figure 4.15 Wet year simulated hydrograph for the Lower Jocko River, comparing the output discharge of a system with (orange) and without (grey) irrigation occurring, and modeled against Compact-derived TIF threshold values (blue).

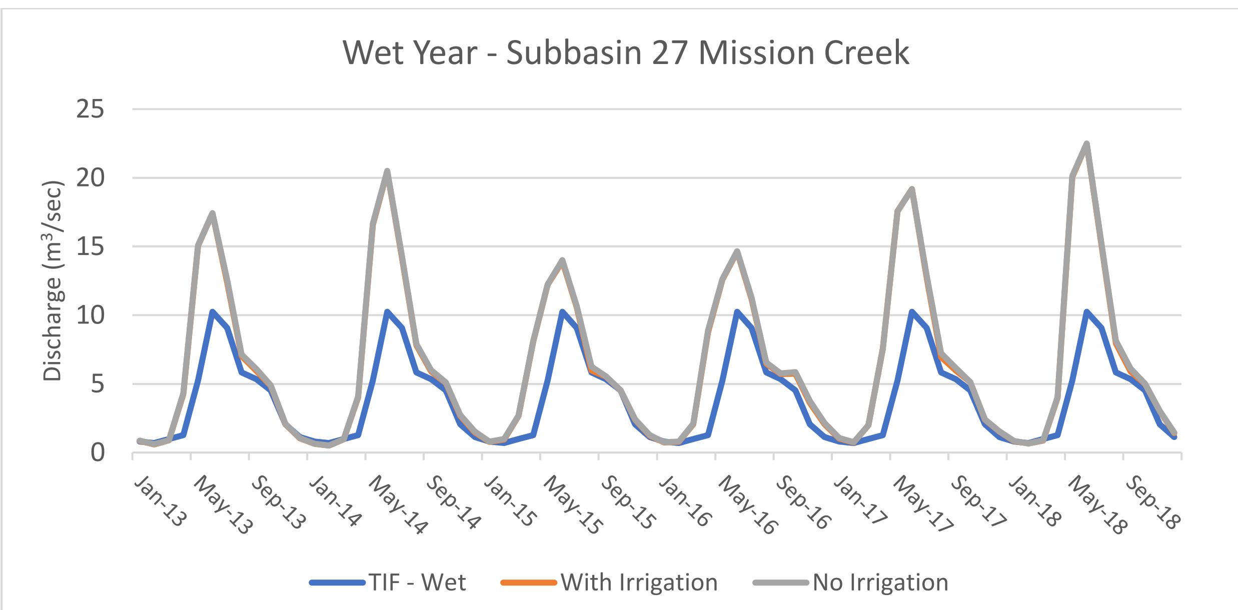

Figure 4.16 Wet year simulated hydrograph for Mission Creek, comparing the output discharge of a system with (orange) and without (grey) irrigation occurring, and modeled against Compact-derived TIF threshold values (blue).

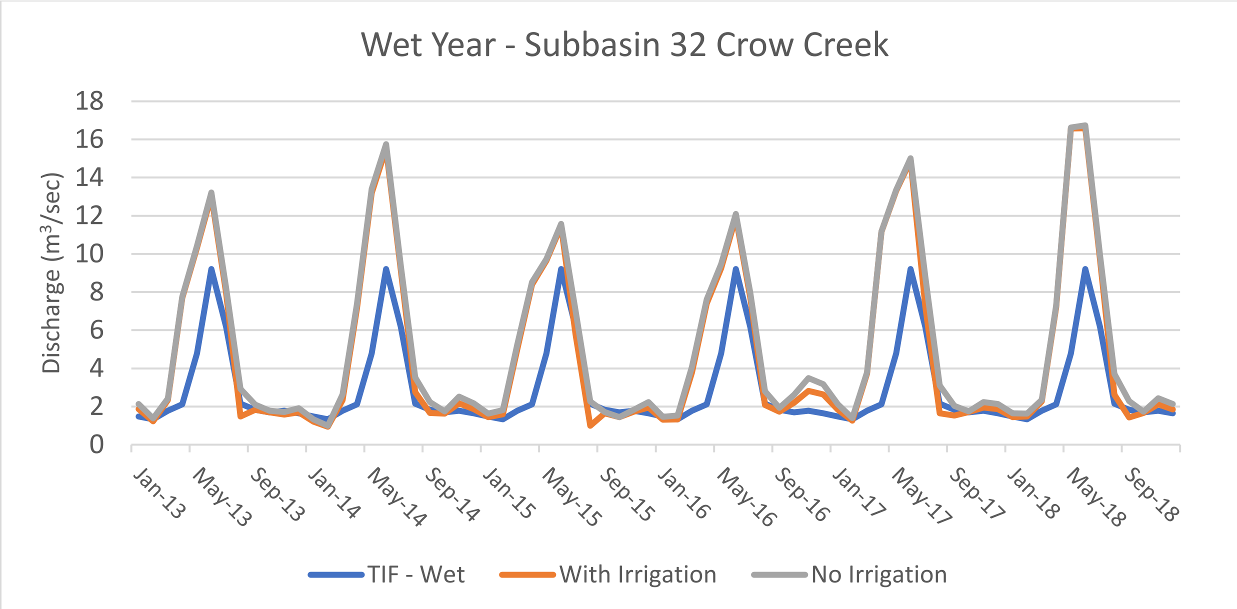

Figure 4.17 Wet year simulated hydrograph for Crow Creek, comparing the output discharge of a system with (orange) and without (grey) irrigation occurring, and modeled against Compact-derived TIF threshold values (blue).

CHAPTER 5. Discussion

In this chapter I discuss significant findings presented in Chapter 4 and delve into why and how these findings are relevant for managing water in the Lower Flathead Basin given the myriad of interests (irrigation, aquatic species habitat) and the potential for a new management paradigm introduced by the CSKT Compact. It is important to note that I decided to focus my investigation of irrigated lands on the cultivation of alfalfa as the most commonly grown and irrigated crop in the region, and by extension, I used the plant water need function in HAWQS/SWAT as a proxy to simulate the amount of water taken out of streamflow for the FIIP system in my model. This is to serve in place of quantifying discharge throughout the FIIP canals and lateral waterways. In this chapter I also discuss HAWQS model assumptions, and why irrigation system efficiency plays a minimal role in influencing subbasin and regional hydrology in the model. Further, I examine the role plant water need (modeled proxy for irrigation amount/scheduling) plays in altering subbasin and regional hydrology, as well as review why dry, normal, and wet year projections in the CSKT compact could play a significant role in shaping subbasin and regional hydrology[1]. I will also (1) discuss some counter-intuitive findings presented in Chapter 4, (2) consider limitations of my research approach, and (3) emphasize key takeaways from this research.

At its core, the following is what I aimed to investigate in this thesis project. Using climate and hydrologic data, the authors of the CSKT Compact created a series of hydrologic

[1] For purposes of this research, "regional hydrology" is defined as the HAWQS simulated watershed (i.e., watershed from SKQ Dam to subbasin 38 – Flathead River at Perma, MT. The term "subbasin" is a renamed version of a "HUC 12" unit (hydrologic unit code), which originated from the USGS. The reason for the distinction is to accurately describe the HAWQS HRU delineation and for analysis purposes. Also, in this analysis I solely focus on the distribution of surface water throughout the FIIP system. This is due to the focus on quantifying and regulating surface water rights in the CSKT Compact and the limitations of HAWQS/SWAT for integrating groundwater modeling.

conditions as stream flow values for subbasins in the Lower Flathead River watershed that would denote whether the subbasin is in a “dry, wet, or normal” condition from year to year. These values were derived from data describing the historical natural streamflow of the Flathead River and tributaries from 1983 to 2002. I took those condition values and used SWAT to create simulations through a time period between 1983 and 2018, for which I had adequate coverage of necessary model input data. I simulated what a consistently dry, wet, or normal hydrograph would look like for comparison against a calibration SWAT model hydrograph in each subbasin to assess how different the dry, normal, wet years would present compared to observed USGS data at the Flathead River at Perma, MT. From this, I assessed how changes in irrigation (e.g., alfalfa water demand) in these different types of years might impact the amount of time that a streamflow would be in or out of compliance with MEFs or meet TIFs.

5.1 HAWQS/SWAT Model Assumptions on Irrigation Efficiency

HAWQS, which uses SWAT as its core modeling engine, assumes that any water lost from system inefficiency is then contributed to the deep aquifer reservoir. This is different from reality because a portion of water lost in the FIIP system would flow in the shallow subsurface to the Flathead River, and/or local tributaries. In reality, return flow to the Flathead River system would serve as an additional source of streamflow to the outlets of individual subbasins and the entire simulated watershed (i.e., outflow of subbasin 38). In SWAT, subsurface return flow can be accounted for as an input to any particular subbasin, just like surface flow in a major tributary. With more of a technical understanding of how much FIIP infrastructure resides in each modeled subbasins, and the general efficiency of that infrastructure, it could be possible to integrate irrigation return flow into future iterations of this model.

A major assumption made in the model is that irrigators are legally using their fully apportioned water right diversion amount; the HAWQS model also cannot account for overuse or underuse of water from an irrigator. This is the case because of the complexity of simulating individual parcels of land that have irrigation rights, as well as the expense and invasiveness of monitoring these water uses over time. It makes sense to use the WSTRS parameter in this case to simulate irrigation withdrawals because there is not a public, robust dataset that highlights instantaneous discharge throughout the FIIP canal system. The WSTRS parameter thus simulates water removed from the system for crop production, which I used to assume FIIP water use in the modeled subbasins.

5.2 Impacts of FIIP Infrastructure Efficiency on Regional Hydrology

In the case of regional hydrology, Flathead River at Perma, MT output hydrographs (subbasin 38) indicated the insignificant role irrigation infrastructure efficiency plays in affecting collective streamflow (see Figure 4.2). However, I initially hypothesized that altering irrigation infrastructure efficiency levels within the model would be detectable because in reality, the inefficiency of the FIIP is a substantial driver of local hydrology (C. Ryan & S. Makepeace, personal communication). There are several reasons why modeled changes in irrigation efficiency did not display the impacts on stream flow that I initially thought it would.

First, the scale at which I was able to run this particular analysis to simulate FIIP infrastructure is at a watershed level (Lower Flathead River Basin), and therefore the detection of any efficiency impacts is diluted with year-to-year fluctuations in natural runoff from small tributaries, and SKQ Dam discharge. It is important to note three sources of water (e.g., FIIP system water, natural runoff from small tributaries, and SKQ Dam discharge) serve as the accumulative outflow of subbasin 38, and by extension the Lower Flathead basin, and tributaries, below SKQ Dam. The total number of subbasins in the simulated watershed is 57 and the total area is just over 5,632 km^2, and this value includes the surface area of the Flathead Lake. Excluding the Lake, the total area of the simulated watershed is ~5,056 km^2. In simulating irrigation efficiency changes across the watershed, irrigated agriculture was identified through land use data, and represents only a fraction of the total land area.

Further, soil types were identified and inputted into the delineation of HRUs in the model (e.g., MT soil classifications MT056, MT135, MT288, MT458), and by extension into all the subbasins in the simulated watershed. The soil data contributed to the determination of overall potential infiltration of the entire Lower Flathead River in that the model only accounts for one soil physical characteristics (e.g., infiltration rates) instead of a variety of types observed in the real world. I hypothesize a reason for this is because HAWQS only accounts for lateral composition of soils and does not capture vertical distinctions in soil type (HAWQS, 2020). Also, the boundaries established for soil type homogenizes each type into one category and then uses the dominant soil type physical characteristics (i.e., infiltration rates) per each HRU in the model. The homogenization of soil types is helpful in this project in order to streamline the simulation process in HAWQS and SWAT Editor, but it is a further abstraction from real conditions.

5.2.1 Impacts of Infrastructure Efficiency on Subbasin Hydrology

In this analysis, I also found that the degree of infrastructure efficiency does not play a significant role in impacting the stream discharge at the outlet of modeled subbasins that have FIIP instream flow rights and grow alfalfa. There are several potential explanations for this. First, the subbasin scale at which I conducted this analysis was large enough to not register (or dilute) the varying degrees of irrigation system efficiency. Recall, I simulated systems operating under 0%, 50%, and 100% efficiency (see section 4.1 and Figure 4.1), and total subbasin areas range from 105.6 km^2 to 1675 km^2 (see Table 4.1). At the subbasin scale, water lost to system inefficiency is dwarfed compared to the amount of water flowing throughout the system, which is determined by the soil moisture deficit of crop demand (R. Srinivasan, personal communication, June 5, 2020). Second, in HAWQS, any water lost from system inefficiency is then contributed to the deep aquifer—and thus 'lost' in the model. This model assumption does not account for return flow in the subsurface to the subbasin mainstream reach. In reality, this unaccounted source of water would contribute an additional source of water to baseflow of subbasin streams in the Lower Flathead River watershed (as discussed above).

Last, and likely most important, is the use of crop water stress threshold as a proxy for historic irrigation diversions into FIIP canals and lateral waterways. I chose to use crop water stress as a proxy because I did not have access to public, long-term datasets that included irrigation and FIIP diversion information. Instead, I used information from the 2018 Montana Agricultural Statistics to obtain average yield values for alfalfa (Sommer, 2018). I then used this value as a water need in the FIIP system (i.e., water to leave the system for consumptive use). It seemed intuitive that efficiency would then be more pronounced and play a large role in model simulations, as it does realistically. For example, in personal communication with CSKT hydrologists, I learned that current FIIP infrastructure operates at close to a 70% inefficiency rate (C. Ryan, personal communication). This means that for all water entering the FIIP infrastructure system, 70% is lost to either seepage or evaporation. Due to this information, at the beginning of this project, my hypothesis was that increasing irrigation efficiency could play the largest role in altering the hydrologic balance of a subbasin through irrigation management actions. At the basin scale, however, this impact is undetectable in the current iteration of the model. However, it is possible that if I decided to analysis specific HRUs, which are unique combinations of slope class, soil type, and land use type, and match these with known sections of FIIP infrastructure, then I might discover more distinct changes in corresponding hydrographs. This level of analysis was beyond the scope of the current investigation but could be promising future research utilizing this modeling approach.

Future research analyses could be guided by Wei et al. (2018). Their team investigated an intensively managed irrigated watershed in the Arkansas River Valley in southeastern Colorado using SWAT. Their team found that accounting for individual cultivated fields, and, more importantly, canal seepage, is necessary to capture the appropriate magnitude of hydrologic processes in the study region, and to accurately represent the timing and magnitude of streamflow events in the Arkansas River and its tributaries. They concluded that of all the features of human management in irrigated watersheds, the inclusion of canal seepage is the most important to represent streamflow in tributaries (Wei et al, 2018).

5.2.2 Influence of Irrigation and No Irrigation on Subbasin Hydrology

Whether a field of alfalfa receives irrigation or not plays a significant role in the simulated outflow of a subbasin, which is generally consistent with my hypotheses. The purpose of simulating irrigation vs. no irrigation was to create a hypothetical scenario in which the CSKT make a senior call on CSKT Compact instream flow water rights on Lower Flathead Basin tributaries, which could potentially stop junior irrigators from irrigating lands in the FIIP influence area. CSKT instream flow water rights in the subbasins I investigated are all dated as “time immemorial” and are thus senior to all irrigation rights upstream from the instream flow measurement point, which we simulated as the outlets of subbasins in which the rights are located.

Future climatic conditions will play a significant role in altering the distribution of water throughout the FIIP system; however, the variability is unknown. It is projected that long term variation in total annual streamflow will be largely influenced by patterns of climate variability, but the direction of influence is unknown (Whitlock et al., 2017). Montana's snowpack has declined in the observational record (i.e., since the 1930s) in the mountains west and east of the Continental Divide; this decline in snowpack has been most pronounced since the 1980s (Whitlock et al., 2017). Warming temperatures over the next century, especially during the spring, are likely to reduce snowpack at mid and low elevations (Whitlock et al., 2017). Further, the MT Climate Assessment (2017) projected that an earlier onset of snowmelt and spring runoff will reduce late-summer water availability in snowmelt-dominated watershed. Historical observations have also shown a shift toward earlier snowmelt and an earlier peak in spring runoff in the Mountain West (including Montana). Projections suggest these patterns are very likely to continue as temperatures increase (Whitlock et al., 2017). The simulated watersheds are certainly affected by the delivery of irrigation water to grow alfalfa, and this scenario could be intensified during the late summer months when available surface water is limited given changing climate scenarios, especially in smaller tributaries.

The Mud Creek (subbasins 33) simulation provides an example of what I hypothesize would happen in this scenario (see Mud Creek in Table 4.1). In dry year simulations, stream discharges fall below MEFs more often in a system with irrigation, for both year-round and irrigation season timeframes. By removing irrigation (simulating a call on junior water rights), there is more water in the stream during all simulations. This subbasin has the largest proportion of area devoted to growing alfalfa of all our analyzed subbasins. The relatively large percentage of land growing alfalfa in the subbasin is likely to be the driver behind the detectability of these effects from irrigation (see map in Figure 4.2 and table 4.1 for percentages; agriculture makes up 28.8% of the Mud Creek subbasin land area). Also, the headwaters of the Mud Creek, and local tributaries, are located in the upper, mountainous area of the subbasin, thus likely susceptible to changes in snowpack and timing of peak flows. These tributaries feed into diversion points in the FIIP system, and FIIP instream flow rights are enforceable at these diversions. The diversion points also serve as point source measurements of inflow to the FIIP. Thus, as climate changes impact the hydrology of Mud Creek (e.g. snow pack in the Mission Mountains), changes in irrigation water demand—whether through a call on senior CSKT instream water rights, FIIP improvements, or other irrigation management actions—could have significant impacts on meeting the MEFs in the subbasin.

As expected, six of the subbasins included in this analysis (i.e., Crow Creek, Lower Crow Creek, Upper Finley Creek, Lower Finley Creek, Upper and Lower Jocko River), all follow a trend consistent with Mud Creek, in that the number of months that fall under an MEF or TIF threshold is greater in a system modeled with irrigation than a system without. This is intuitive because when additional water is taken out of the stream and diverted to FIIP infrastructure, there is inherently less water available as instream flow. This reinforces that in drainages with irrigated agriculture (FIIP) and CSKT instream flow rights, meeting minimum and target flow requirements will likely require some adjustments to irrigation demand.

The modeled output of Post Creek serves as a counter example to Mud Creek, in that when irrigation is halted in the model, there is less water in the stream and more time detected below MEF and TIF threshold values. Post Creek is relatively small compared to the eight other basins (118.4 km^2). The area of the subbasin growing alfalfa is also small with an area of 5.4 km^2, which makes up only 4.6% of the total subbasin area (see Table 4.1). In Figure 4.2, it is apparent much of the subbasin is headwaters, located in the Mission Mountains with small amounts of noticeable parcels of historically irrigated acreage scattered in areas of lower elevation. It is also important to recognize that when I simulated no irrigation in the FIIP system, this also includes cessation of diversion of any water captured as mountain runoff. Time detected above MEF or TIF thresholds is greater when irrigation is halted than when it is occurring; this seems counterintuitive at first, however considering the small proportion of land designated for alfalfa and a significant portion of mountain runoff diverted into the FIIP system, it may make sense. In a scenario with no irrigation, there is also no diversion of mountain runoff for local use. Stream flow will then leave the subbasin at the time of runoff, potentially increasing late season vulnerability to falling below MEFs and TIFs due to drought and earlier timing of runoff. This finding also highlights that the potential for senior call on the river may not help in this situation because of the minute area devoted to growing alfalfa and the interaction with climatic changes predicted for the region.

Results from Mission Creek (subbasin 27) are also unexpected in that the modeled simulation with irrigation, shows less days of stream discharge falling under MEF and TIF thresholds, compared to a scenario modeled without irrigation. Additionally, during an irrigation season only scenario (mid-April to mid-September), the subbasin follows suit with Mud Creek in that when irrigation is taken away, then there are less days where subbasin outflow is below MEF and TIF threshold values (see Mission Creek in Table 4.1). In the “no irrigation” situation, the expected trend may be attributed to the small area and proportion of land growing alfalfa and hay (i.e., 6.6 km^2 in a total area of 218.3 km^2; 3% of total area).

These results reinforce the importance of potential climatic changes in determining the changing hydrology of the FIIP system and Lower Flathead basin, but also the options that the

CSKT, the State of Montana, and local water users choose to manage irrigation and water use, specifically in the subbasins I modeled. Differences in subbasin hydrology (e.g. drainage area size, amount of water diverted for irrigation, and subbasins location related to headwaters and/or snow line) will interact with changing patterns of precipitation to impact streamflow differently. Depending on these interactions, ceasing irrigation or increasing irrigation efficiency may the best tool to meet minimum and target flows to meet legal standards and aquatic habitat protection goals in some subbasins, particularly those with a larger percentage of irrigation (e.g. Mud Creek). In other subbasins, such as those will much less irrigation as a percentage of land area and in predominantly higher elevations (headwaters), ceasing irrigation may not be the right management option. Instead, irrigation may be a tool to provide for late season flow and a decrease of time out of compliance with MEFs and TIFs. More research is needed to better understand other factors of the modeled watershed that account of differences in the reaction of simulations with and without irrigation across a wider spectrum of climate scenarios.

Streamflow discharge may be another factor worth investigating for important interactions between climate scenarios, irrigation, and instream flow. In simulating irrigation in the Lower and Upper Jocko Rivers, the two subbasins do not fall under MEF or TIF threshold values in any scenario. Partially due to the large size of the two subbasins (Upper Jocko River subbasin has an area of 720 km^2 and Lower Jocko River 1,675 km^2), the discharge from these two subbasins is an order of magnitude greater than most of the other subbasins analyzed. Also, note that both subbasin have a proportion of the total area growing alfalfa is less than 2% (see Table 4.1). The combination of subbasin size, cumulative discharge at the outlet and small amount of area growing alfalfa is likely the main contributing factors to MEF and TIF compliance in the modeled scenarios. However, the Jocko River system and tributaries are critically important as providing aquatic habitat for culturally-significant fish species. The CSKT have focused many stream restoration efforts on these reaches, which may merit a close investigation of what is water is needed under climate scenarios beyond the Compact's MEFs and TIFs.

Topography may also play a role in influencing the vulnerability of each subbasin, however there are not any obvious correlations between slope and the ability of a subbasin to stay above MEF and TIF thresholds. In HAWQS, HRUs were constructed to aggregate all slope classes into one class per HRU. Therefore, if more slope classifications were constructed in the model and considered in this analysis, then perhaps different trends could be uncovered. The location and number of diversion nodes that capture natural streamflow from the Mission Mountains play a role in why certain subbasins become more vulnerable with a river call, and vice versa, but the degree of influence is unknown in this analysis. With the future onset of climate change and an increase of hydrologic variation, especially in the western United States and specifically in Western Montana, there is potential for earlier snowmelt in the early spring and increased rain in the winter (Whitlock et al. 2017). This shift in hydrologic regime has the potential to adversely affect the resilience of subbasins to remain above MEF and TIF thresholds specifically related to reservoirs that exist on the reservation that hold mountain runoff. In scenarios where snowpack melt occurs earlier in the season, much of that water might need to be discharged into the Flathead River when reservoirs are filled faster earlier in the season, thus leaving the system in the early spring. This is certainly a major challenge the CSKT and FIIP managers will need to address in the coming decades, as well as the presence of a decreased snowpack overall. At this moment, our model simulations do not account for the shift in the hydrology regime (e.g., earlier snowmelt and more winter rain). The climatic variations inputted into the HAWQS model is derived from modeled natural streamflow of the Flathead River (see section 3.5.1), which means that a dry, normal, or wet year follows the annual discharge peak in the early summer.

Many of these diversion points in the model used to simulate FIIP withdrawals and CSKT instream flow rights are located above many of the reservoirs and irrigated agricultural lands located in the FIIP influence area. The HAWQS model does not account for the fact that these reservoirs play an important role in the distribution of FIIP system water, and the scenarios investigated herein do not take into account the impact of the majority of agricultural lands in the FIIP area because no CSKT instream flow rights exist below these areas to analyze in context (this is not necessarily a limitation of the model, but a reminder of the need to consider how and why the CSKT instream flows rights were established). Instead, HAWQS considers the SKQ Dam, and by extension the FIIP pumping station, as a point source input of water along with precipitation and mountain runoff. In a way, HAWQS consolidates water input sources into the FIIP system, when realistically, the reservoirs add much complexity to the system and provide water to the system year-round. A future analysis incorporating reservoir storage and discharge would be worthwhile in the future to investigate its contribution of increased efficiency of the FIIP system. In addition, it would be interesting to investigate the impact of the majority of irrigated agriculture within the FIIP system on the downstream tributaries and aquatic habitat, despite the presence of enforceable instream flow rights only in upstream reaches.

In the analysis of these subbasins, a recurring question presents itself: would a senior call on the tribal instream flow rights serve beneficial in the absence of FIIP infrastructure improvements? My modeling suggests that it could be relatively helpful in most subbasins, except for in Post Creek and Mission Creek, which are outliers in that in scenarios of ‘no irrigation' the subbasins becomes more vulnerable to falling under its MEF or TIF thresholds. A senior call on the Flathead River tributaries could decrease the vulnerability of flows in sensitive streams where CSKT instream flows exist (see Crow Creek, Mud Creek in Table 4.1), and in some instances safeguard a subbasin's ability to remain above its MEF and TIF threshold (see Mission Creek, Lower Crow Creek, Lower and Upper Finley Creek, and Lower and Upper Jocko River in Table 4.1). However, it is also the case that a more nuanced analysis of climate changes (including influence of changing snowpack dynamics and altered runoff timing), irrigation efficiency, and subbasin position or structure, may yield more targeted management approaches for each subbasin during various climate scenarios that could be more beneficial than a blanket call on junior water rights holders.

5.3 Impacts of Water Stress Threshold (WSTRS) on Regional and Subbasin Hydrology

The impacts of water stress thresholds on regional hydrology is minimal with little variability in discharge values in the subbasins analyzed. Water stress impacts are similar to the system efficiency in that, at the regional level, there is little to no impact on the outflow of the entire simulated watershed at the outlet of subbasin 38 – Flathead River at Perma (i.e., regional hydrology). Recall the term WSTRS signifies the water stress threshold that triggers irrigation, which allows users to apply water as needed to each plant type (e.g., alfalfa). There are a variety of potential explanations for the minimal impact that water stress has on region hydrology, which I review below.

First, the scale analyzed is quite large. Recall, the total area of the simulated Lower Flathead River watershed is approximately 5,632 km^2; the range of subbasin areas analyzed varies from 105.6 km^2 to 1,675 km^2 (see Table 4.1). A WSTRS value of 0.9 indicates that a field is watered every week, and a WSTRS value less than 0.9 means the crops are watered less frequently (R. Srinivasan, personal communication, April 10, 2020). The amount of water not applied to a crop because of a lower WSTRS value is tiny compared to the amount of water flowing through the system. With this knowledge and what is displayed in Figures 4.3 through 4.8, I conclude that water stress, alongside efficiency, does not play a pivotal role in changing the downstream discharge of each subbasin. The same could be said for Figure 4.1, where at the simulated watershed outlet water stress still does not alter regional hydrology to any measurable degree.

Second, it is important to note that plant water stress is a finite value, in that any more water applied to grow the plant is not useful for the crop. Therefore, the amount of water needed for each crop type is capped because of the water demand. With that said, this deviates from reality in that much of the water applied to the FIIP system is through flood and sprinkler irrigation, which is capped at the amount of water the irrigator can legally and physically apply. This disconnect between water for plant need (e.g., WSTRS) and water allocated into the FIIP system is vital to point out. I would hypothesize that alfalfa does not fully consume the allocated FIIP water, thus leaving “unused” water in the system flowing into the Flathead River. In other words, water allocations to the FIIP may be much larger than the amount of water needed to grow alfalfa. This possible gap in water need may explain why we are not seeing distinct variability in subbasin outflow. On the other hand, this gap in water need could prove to be helpful for the Tribe in allowing members to expand the growth of alfalfa, so that the “unused” water could then grow more crops. A future analysis could investigate these same scenarios, except at an HRU scale, which might provide more insight into how water stress may alter the hydrology of an isolated location of the FIIP influence area. It would be interesting to visualize any hydrologic changes between an HRU with 100% of the area growing alfalfa and an HRU growing no alfalfa. That possible investigation could then provide a way to target smaller areas of the FIIP system that would need infrastructure improvements.

5.4 Impacts of Dry, Normal, and Wet Years on Regional and Subbasin Hydrology

At the regional level, the simulation of a dry, normal, and wet year played the most significant role in altering the hydrology of the Lower Flathead River watershed. Recall, the determination of a dry, normal, or wet year for the purposes of defining RDAs, MEFs, and TIFs was based on modeled natural streamflow for the April through July forecasting period of the 1983 – 2002 study period by the authors of the CSKT Compact. Dry years are the four years for which the April – July natural flow is below the 80th-percentile exceedance level. Wet years are the four years natural flow is above the 20th-percentile exceedance level, and normal years are those falling between the two exceedance levels (CSKT Compact, 2015). The authors of the CSKT Compact came up with these characterizations of hydrologic regimes as well as corresponding, enforceable instream flow values for each type of year, wet, normal, and dry to protect streamflow and associated values such as aquatic species habitat. Because the Compact authors envisioned the Compact working in conjunction with a Settlement Agreement that would provide for improvements in FIIP infrastructure, I wished to investigate how varying hydrologic conditions (wet, normal, dry) would affect the subbasins ability to remain above enforceable and target instream flow values without FIIP improvements (see Table 4.2 and Figures 4.9-4.17). Below I present a variety of reasons why simulated hydrologic conditions (i.e., dry, normal, and wet year) expressly impact the downstream outflow of the nine subbasins in this analysis.

First, since I solely considered the crop water stress, and by extension annual statistical averages of alfalfa crop yields in western Montana, a misalignment of the amount of crop water needed versus water allocated into the FIIP system (i.e., RDA) (Sommer, 2018). A first look at Figure 4.2 suggest there is a substantial amount of agricultural land outside the nine subbasins included in this project analysis. It is important to note that 32 FIIP instream flow rights exist for the CSKT Compact (see CSKT Compact Appendix 11). These rights hold a time immemorial priority, which is directed towards improving regional aquatic environments, while simultaneously providing FIIP irrigation water. From there, I visually identified and aggregated the source name and tributary associated with the water right into regional HUC 12 units; that left 15 HUC 12s that possess FIIP instream flow rights and irrigated FIIP agriculture. Further, I filtered out those HUC 12 units that did not grow alfalfa, with help from the 2018 Montana Agricultural Statistics; this left the nine subbasins that have a FIIP instream flow right and grows alfalfa (Sommer, 2018).

These nine subbasins hold both a quantified adjudication of water and a crop water need for growing alfalfa; these two values are not the same. Further, farmers are not growing alfalfa every year, so the total acreage of alfalfa grown in the HAWQS model is not fully utilized by irrigators on a consistent annual basis. In other words, there are years where fields are fallow, allowing for the revitalization of soil. As a reminder, HAWQS obtains its land use information from the NASS Cropland Data Layer and the National Land Cover Dataset (see Table 3.2) (Fry et al., 2011; HAWQS, 2020). Since crop type water need has a peak threshold, a surplus amount of water applied from the FIIP pumping station, natural mountain runoff, and precipitation, then flows downstream. When more water is contributed into the system from the pumping station, and the crop water need remains stagnant, more water flows downstream.

However, as much as the application of irrigation water helps subbasins stay above MEF and TIF threshold values (except for Mud Creek) (see table 4.1), this model does not account for projected discharge peak changes in the spring from earlier snowmelt (i.e., potential changes in runoff time and amount) (see section 5.2.2) (Whitlock et al., 2017).

Additionally, this project model does not capture groundwater flow, mountain-front recharge, evaporation from open canals, and the effects of increased temperatures associated with a warming climate. As the climate warms and temperature increase, I suspect the role of evaporation will rise as well, particularly for open water bodies (e.g., FIIP open canals). A further investigation could look at the effects of a changing hydrologic regime, while potentially examining the role groundwater plays in Lower Flathead River hydrology. Future work could accomplish this by using the coupled SWAT-MODFLOW modeling code (Bailey et al., 2016), which can represent transient groundwater flow processes in heterogeneous aquifer systems (Wei et al, 2018). Last, additional work might explore if mountain-front recharge and canal evaporation outputs are large enough to modify the watershed in a warmer climate.

5.5 Limitations of this Study

Several limitations became apparent during the model building process and during the analysis of this data, particularly limitations of the HAWQS and SWAT models.

As previously discussed, the HAWQS/SWAT model does not account for subsurface return flow to major tributaries of the Lower Flathead River from irrigation system inefficiencies (i.e., water loss). Instead, HAWQS recognizes that any water lost from system inefficiencies is then contributed to the deep aquifer, thus leaving the system (R. Srinivasan, personal communication, June 5, 2020).

Information on the discharge of water throughout the FIIP system canals and lateral waterways was not obtainable during the time of this study. Instead, I used a crop water stress threshold value as a proxy for water need in the FIIP. This proxy is limiting because it does not consider the method of irrigation (i.e., flood or sprinkler system), and considers the water need of alfalfa instead of observed canal and lateral flow. This distinction potentially underestimates the total water use of the FIIP system, along with any other system inefficiency parameters I do not consider, such as accuracy and continuity of discharge data. Also, at the time of this study, data on observed watering frequency in the subbasins investigated was not available.

During the modeled simulations of the impacts of CSKT-Compact derived hydrologic conditions (i.e., dry, normal, and wet year) on the FIIP, I did not consider a potential shift in peak discharge during the spring from earlier snowmelt and decreased availability of water during the summer months (Whitlock et al, 2017). Further, this study did not capture potential increased aridity basin-wide associated with a warming climate and increased rainfall during winter months.

Although likely capable of simulating the role of reservoirs in the distribution of water throughout the FIIP system, I did not input reservoir information into HAWQS/SWAT during model simulations for this project. I intended to reduce complexity in modeling the system; I identified the FIIP pumping system as the main point source input into the FIIP. Had reservoir information played a more active role in this analysis, I hypothesize we would see a slight decrease in the vulnerability of subbasins to stay above their MEF or TIF threshold during the summer months (e.g., August and September have less months falling under MEF or TIF thresholds).

A significant limitation to this study is in relation to how the Compact determines the measurement locations of MEFs, which is mostly upstream of most agricultural operations (i.e., at the foot of the Mission Mountains). Therefore, agriculture in this analysis, by design, is not a driving factor in the streamflow of streams with enforceable instream flows. This is because the cultivation of alfalfa in these subbasins (n=9) makes up a small percentage of the total area (see Table 4.1). There are certainly other areas of the FIIP influence area where subbasin land area is more dominated by crop land, except those subbasins do not hold FIIP instream flow rights, and thus there is not a discharge threshold by which to analyze stream segments that has meaning in terms of other Compact/Settlement values (e.g. aquatic habitat of culturally-significant species). In the subbasins with predominant crop coverage, I suspect irrigation efficiency and water stress thresholds to play a more significant role in altering subbasin hydrology.

The potential shift in hydrologic regime (i.e., spring peak associated with earlier snow melt, less water available in later summer month) is an alteration in the Lower Flathead River basin the CSKT should prepare for. Again, an analysis including the multiple reservoirs in the FIIP influence could shed additional light on the resilience of the system to climate changes and the ability to deliver irrigation water to the FIIP system during August and September.

CHAPTER 6. Conclusions

There are likely myriad ways to interpret my research findings—but it is critical to keep in the mind the background and context under which I pursued this research project. Irrigation and water rights in the Flathead Valley have been contentious issues for close to a century, whether in public view or not. This is apparent in the amount of time it took to negotiate the CSKT Compact, as well as the continued unwillingness of Congress to pass companion Settlement legislation. Once that occurs, I do not see much opposition from the CSKT populace and Tribal leadership, or from the Montana Water Court in decreeing the Tribal water rights laid out in the Compact. However, I cannot place myself in the shoes of a CSKT tribal member, nor the shoes of a non-Native irrigator in the Flathead Valley. If anything, the take away the message is that the resilience of livelihoods and environments of the Flathead Valley are intimately tied to the ability to deliver water allocations to all water users; this, in turn, is dependent on the cooperation of all water users including irrigators, wildlife managers, the State of Montana, the CSKT, the federal government, and others. Any water overuse may not be detected now in the collective discharge of the Flathead River, but with the onset of climate change including warmer temperatures and decreased snowpack, and a steady population increase in the region, that may change. With the possibility of less surface water available during the summer months, a shift to using groundwater is a possibility, which could then affect the ability of groundwater to provide baseflow to surface water rights. If surface water rights are not met, then that would mean curtailments of junior surface and groundwater right holders. At the end of the day, a senior call on the Flathead River or its tributaries is not what anyone wants, therefore a proactive approach to building a resilient system of water allocation is best for everyone. I believe the CSKT-Montana Water Compact, and associated CSKT Water Settlement, are meaningful steps in the direction for Tribes to plan seven generations in the future. It is not only helpful for the Tribe, but for legacy irrigators in the Flathead Valley; it recognizes their rights in the "totem pole" of water right seniority, thus securing future consumptive water use.

In this case of the CSKT-Montana Compact and associated CSKT Water Settlement, I have come to suspect that the negotiation process to settle tribal water claims can take many forms—often beyond the law. This one Compact and Settlement is to reach an end in the legal system, which is to quantify the legal claim of water for the CSKT in the Lower Flathead River watershed. With that said, all vested stakeholders came to the table and negotiated the terms of the agreement, and eventually came up with a way to harness the FIIP system to ensure the availability of water in the coming century for agriculture and aquatic systems. By planning to improve the system efficiency to undertake potential future hydrologic conditions the CSKT is preparing for changes in the Flathead Valley. The Compact provides flexibility by providing a range of potential streamflow values (i.e., dry, normal, and wet years), and according to my findings, has room to use the FIIP in all scenarios to prepare for and meet a range of climate scenarios and instream flow needs. Considering all this information, I am convinced a federally-recognized Tribal Nation pursing the avenue of negotiating a water rights compact and settlement is a prime example of adaptive governance in practice. The settlement process triumphs over the costly and lengthy process of adjudicating reserved rights in the Montana Water Court and provides flexibilities and contingencies for change that would not exist under straight adjudication of these water rights—specifically a change in hydrologic conditions driven by climate changes.

In regards to the settlement process for federally-recognized Tribal Nations, Cosens and Chaffin (2016) found that the past four decades of settlement of Native American water rights in the United States offer a window on what happens when the law alters the relative power among communities sharing a scarce water source and a chance to study the emergence of adaptation and innovation as communities respond to this new paradigm. This window also provides a means to consider the role of the legal process (i.e., settlements) in assuring the accountability, transparency, fairness, and inclusiveness in these local emergent collaborations (Cosens & Chaffin, 2016). The authors also mention that adaptive, collaborative, and new governance mechanisms hold promise for the innovation and adaptation needed to respond to the challenges of water scarcity in the current millennium, but it is clear that they do not emerge in a vacuum (Cosens & Chaffin, 2016). The elevation of tribal water rights in the U.S. legal system (state and federal) provided the political power and leverage for the CSKT to negotiate for increased sovereignty over water and associated resources, but in turn, they gave up a substantial amount of 'potential' water rights outside of their reservation in the process. This research was not intended to analyze that tradeoff, but instead to provide insight on how the CSKT might best administer the rights gained on reservation to achieve goals of habitat and species conservation as well as adaptability to inevitable environmental change.

From the angle of the Montana DNRC—the State agency charged with administering water rights—this can also signal relief as the agency will be able to legally recognize the Flathead Reservation Water Management Board as holding jurisdiction over water rights on the Flathead Reservation (CSKT Compact, 2015). This will transfer the jurisdiction of distributing water rights on the Flathead Reservation to the Flathead Reservation Water Management Board, thus relieving the Montana DNRC of that duty for the Flathead Reservation and providing some much-awaited legal certainty for water users in the basin.

The use of hydrologic modeling is incredibly important moving forward, in the context of managing water on the Flathead Reservation, and Lower Flathead River watershed at large. The use of HAWQS to answer my research questions is one pathway, of probably hundreds of alternative routes, to reach the same end. This hydrologic model and thesis project provide a foundation for future hydrologic researchers to build upon in the future. There is ample room to adjust parameters in the HAWQS/SWAT model I built, run new hypothetical scenarios, and provide more insight into the vulnerability of subbasins falling under MEF and TIF threshold values. I am confident in the general trends found in my results such as the importance of climate variability as a driving variable to meeting MEFs and TIFs, the little to no influence of system efficiency and plant water stress (irrigation demand) on regional hydrology, but the potential to use irrigation infrastructure to navigate climate impacts on hydrology in some subbasins. My findings also highlight that a traditional (all or nothing) senior call on the river may help in most subbasins because of the relative area devoted to growing alfalfa, and the variable influence of irrigation on stream flows in modeled simulations. During an irrigation season period of time (mid-April to mid-September) eight of the nine subbasins highlighted in this study could benefit from a senior call made on the Lower Flathead River; all except for Post Creek. Future work can certainly build upon these findings, specifically by isolating key combinations of driving variables (e.g. size, discharge, crop area, topography) that denote which subbasins would benefit from call, or other strategies such as irrigation efficiency improvements, or stream restoration. Potential recommendations I would make moving forward would be to prioritize the rehabilitation of Post Creek, Mud Creek, and Lower Crow Creek, because these three subbasins have the most months fall under MEF and TIF threshold values during an irrigation season with irrigation occurring. I would recommend investigating the behavior of Post Creek more in depth;

perhaps altering the slope classification of the subbasin would help, as well as analyzing HRUs in the subbasin that grow a substantive amount of alfalfa.

Future work pertaining to hydrologic modeling of the FIIP system could take many forms. Wei et al. (2018) team concluded in their study that of all human management in irrigation watershed (e.g., Arkansas River Valley and Flathead River Valley), the inclusion of canal seepage is the most important to represent streamflow in tributaries (Wei et al., 2018). That approach could certainly be applied to future studies in the Lower Flathead River watershed, as well as analyzing specific HRUs in the SWAT model, potentially building HRUs (or groups of HRUs) that mimic the drainage districts of the FIIP to more closely simulate the hydrology of the project. The impacts of irrigation seepage at the HRU, or even individual parcel level, is certainly an area of research worth pursuing in future studies. Through the HAWQS interface, and SWAT editor, a user could run the simulations they wish and export the necessary HRU information (e.g., crop yield, biomass, water stress days, and irrigation amount) to analyze the effects of irrigation efficiency on the HRU hydrology (R. Srinivasan, personal communication, May 16, 2020). Another avenue that may be worth pursuing is to extract more detailed crop information for alfalfa from HRU output files, like yield, number of water stress days, and biomass, to add resolution to identifying which parts of the FIIP are vulnerable of falling under MEF and TIF thresholds.

In future work the incorporation of reservoirs into the FIIP hydrologic system would certainly be worthwhile; the FIIP system includes 15 reservoirs and dams in the influence area. In reality, these reservoirs serve a vital role in providing the system irrigation water during the late summer months, as well as provide habitat to many aquatic species in western Montana. The complexity of reservoirs in the system was not considered in this analysis. Further, integrating the influence of groundwater on the FIIP system is important work to be done in the Lower Flathead River. This could be accomplished by harnessing the coupled SWAT-MODFLOW modeling code (Bailey et al., 2016), which can represent transient groundwater flow processes in heterogeneous aquifer systems (Wei et al., 2016). Also, exploring the heterogeneity of the shallow and deep aquifer underneath the Flathead Reservation would be interesting, and shed more light on the influence and potential of groundwater to meet water use needs in the basin. With impending hydrologic changes associated with climate changes from information taken from the 2017 Montana Climate Assessment, groundwater will likely play a more active role in challenging the resilience of the FIIP water delivery system.

Overall, better understanding the complexity of the FIIP system is worthwhile work. It is an expansive amount of irrigated land, with large portions of the landscape isolated from one another. In other words, different parts of the FIIP influence area are fed water from diverse sources. Thus, the scale of analysis is important moving forward. Luckily, with technology, we can model changes from the CSKT Compact at a watershed and HRU scale fairly easily, using HAWQS and SWAT.

Takeaway Messages

The Confederated Salish and Kootenai Tribes of the Flathead Reservation is a sovereign nation. Period. Their roots, identity, language, culture, etc., are directly linked to their homeland, in and outside the boundaries of the Flathead Reservation. This connection predates any European concept of “water rights” or “land ownership”, and for centuries they fought to retain their ways of life and worldview; this fight continues today. This must be recognized, honored, and actively remembered by those reading this thesis document. Learn the history of Indigenous Peoples in the Western Hemisphere, then hopefully it will garner a better perspective in why it is important to cultivate a robust Tribal Nation that flexes its sovereignty as a domestic-dependent nation in the United States. Water rights serve a huge benefit for federally-recognized Tribal Nations, especially in the western U.S.; therefore, shattering the culture of water right quantity ambiguity for tribal water rights is imperative moving forward. As a Nation, we are moving slowly in this direction. It is evident in the amount of Indian water rights settlements that have been enacted into federal law (36 settlements with 40 individual Tribal Nations as of this thesis publication) (Stern, 2019); however, there is a tremendous amount of work to be done to settle potential water claims of over 500 additional federally-recognized Tribal Nations in the U.S.

Moving forward for the Flathead Valley, the decades of work put into the investigation and negotiation of the CSKT-Compact, and CSKT Water Settlement, should not be wasted. It is clear the CSKT wish to pursue the route of negotiating a settlement agreement with non-CSKT members also residing in the Flathead Valley. Had that not been the case, this thesis project would not exist. A culture of cooperation, compromise, and empathy is integral for all water users to practice in the coming decades. According to my study, irrigation efficiency and crop water need will not be the largest player in meeting irrigation and FIIP instream flow rights. It is future hydrologic conditions that will be the biggest influencer in effecting the entire Lower Flathead River watershed, and this is a factor no one can control. However, my research has highlighted the role that irrigation could play in some basins in building resilience to hydrologic impacts of climate change. Therefore, as aforementioned, a proactive approach to building an irrigation and allocation system (e.g., enacting CSKT Water Settlement) that ensures the resilience and sustainability of all livelihoods and environmental needs is best for everyone.

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^Data source is owned by the Confederated Salish and Kootenai Tribes, and is not public.